Parenting Gets Under the Skin: Mother-Child Physiological Synchrony and Child Self-Regulation in Post-Deployed Military Families

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Abstract

Parent-child physiological synchrony, which is characterized by the matching or concordance of physiological states among parents and children, has been theorized to be linked to children's self-regulation and adaptive outcomes. However, the link between physiological synchrony and child regulatory outcomes was rarely examined in empirical studies, especially in the at-risk populations (i.e., post-deployed military families). Also, no research has investigated the impact of parenting interventions on physiological synchrony. Study 1 employed a multilevel growth modeling approach to model dynamic changes in respiratory sinus arrhythmia (RSA) during a dyadic problem-solving task, and results showed a positive association between physiological synchrony and child self-regulation. Also, younger children tended to show positive lagged synchrony with mothers while older children tended to show negative lagged synchrony. Mothers' emotion dysregulation was found to be associated with higher levels of lagged synchrony. Additionally, synchrony was found to be linked to both positive (i.e., fewer displays of anger/disgust, more positive physical behaviors, and less negative directive behaviors) and negative parenting behaviors (i.e., fewer displays of positive affect). Study 2 explored the effect of the After Deployment, Adaptive Parenting Tools/ADAPT parenting intervention on dyadic synchrony, as well as the moderation effect of synchrony at baseline on the indirect intervention effect on child self-regulation through changes in parental emotion socialization. Although the hypothesized intervention effect was not observed, dyads with negative synchrony at baseline were found to benefit more from the ADAPT intervention. The changes in emotion socialization behaviors were further associated with better child self-regulation. These two studies highlighted the importance of parent-child physiological synchrony in self-regulation development in children in military families who are at risk for developing maladaptive behaviors. The implications and future directions are discussed.

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General Introduction

Parent-Child Interaction in the Context of Parental Deployment

Since 2001, nearly 3 million U.S. service members have been deployed to war in Iraq and/or Afghanistan for Operations Enduring Freedom (OEF), Iraqi Freedom (OIF), and New Dawn (OND). National Guard/Reserve (NG/R) members have been deployed at unparalleled rates (Office of the Deputy Under Secretary of Defense, 2015). They are, on average, older and more likely to be married and have children compared to active duty personnel. Wartime deployment place stressors not only on service members but on military families. Stress and adjustment difficulties related to deployment persist during reintegration and may extend beyond individual service members to present substantial challenges for civilian partners and children. Although most children are resilient, evidence has shown that children with deployed parents are more likely to exhibit externalizing behavior problems, emotional distress, and poor academic performance (Chartrand, et al., 2008; Mansfield et al., 2010) compared to their peers.

Effective parenting behaviors and positive parent-child relationships shape children's emotion regulation and social-emotional adjustment (Eisenberg et al., 1998). Difficult transitions, however, can be stressful for parents, rendering them less effective (e.g. more impatient and coercive) with their children. The military family stress model suggests that the negative impact of parental deployment and mental health problems on children's behavioral problems are primarily mediated through compromised parenting (Gewirtz et al., 2018a). Parenting is a multi-dimensional concept, and one important aspect of parenting involves the socialization of children's emotion-related functioning, also known as emotion-related parenting practices/ERPPs (Morris et al. 2007). In military families with a reintegrating service member, exposure to combat trauma and subsequent mental health problems may compromise ERPPs (Brockman et al. 2016). Family interactions can be emotionally charged, and parents may need to deal with their children's emotions while struggling with their own mental health problems, such as posttraumatic stress symptoms (PTSS), depression, and anxiety (Erbes et al. 2011). Parents experiencing posttraumatic distress may show less emotional attunement and psychological flexibility to tolerate unwanted thoughts and feelings (Kashdan, & Rottenberg, 2010). They may avoid emotionally charged situations (e.g., interactions with children) by becoming emotionally unavailable and numb. Avoiding discussing emotions or minimization of children's negative emotions appear to be linked to impairments in children's emotion regulation and may further escalate the display of negative emotions (Gottman et al., 1996; Snyder et al., 2013). Therefore, combat exposure and subsequent psychopathology symptoms may interfere with military parents' capacities to respond constructively to children's strong emotions.

Physiological Underpinnings of Child Self-Regulation

Top-down self-regulation, broadly defined as the ability to volitionally regulate emotion, cognition, and behavior in response to internal changes and environmental demands, has been consistently found to play an important role in children's socioemotional development (Bradley et al., 2011; Eisenberg et al., 2010; Graziano et al., 2010). Top-down self-regulation is a complex and multi-component construct, and it has been generally differentiated into two interrelated components: emotional self-regulation and behavioral self-regulation (Bridgett et al., 2015). Emotion self-regulation, or emotion regulation, which reflects the process of modulating the occurrence, duration, and intensity of internal feeling states (both positive and negative) and emotion-related physiological processes (Eisenberg & Spinrad, 2004), may serve as a transdiagnostic factor in the development of internalizing and externalizing problems (Aldao et al., 2016). Behavioral regulation, consisting of executive functioning, effortful control, and self-control, reflects individual differences in the ability to modulate cognitive processes (e.g., shift the focus of attention and inhibit dominant responses). The strong link between self-regulation difficulties and child adjustment problems (i.e., internalizing problem behaviors, externalizing problem behaviors, and impairments in social competence) has been widely established in the literature across different developmental stages (Eisenberg et al., 2001; Rydell et al., 2003; Spinrad et al., 2006).

The functioning of the autonomic nervous system (ANS) has been widely found to reflect self-regulatory processes. In fact, a meta-analytic review proposed that indices of heart rate variability (e.g., respiratory sinus arrhythmia/RSA) may be biomarkers of top-down self-regulation (Holzman & Bridgett, 2017). The ANS consists of two reciprocal innervated branches, the sympathetic nervous system (SNS) and parasympathetic nervous system (PNS). The SNS functions in response to external challenges by mobilizing the existing reserves of the body, whereas the PNS fosters restoration and repair in the absence of external challenges (Porges, 2011). According to Porges' (2001) Polyvagal theory, the PNS exerts control over cardiac activity through the vagal nerve to regulate an individual's emotional arousal to an external stimulus. In other words, the vagus nerve functions as a brake, inhibiting the activation of the SNS and facilitating relaxation and social engagement behaviors in a safe environment. When a situation is perceived as stressful, the vagal brake will be withdrawn, which enables rapid mobilization and a “fight or flight” response. Therefore, cardiac vagal regulation is regarded as a physiological manifestation of emotion regulation in social situations.

RSA is an index of cardiac vagal tone (i.e., the rhythmic fluctuation in heart rate during the respiratory cycle), which reflects the regulation of cardiac arousal by the parasympathetic nervous system via the vagus nerve (Porges, 2007). During inspiration, heart rate increases due to vagal suppression, and heart rate decreases during exhalation due to vagal regulation. Two aspects of RSA have been measured related to emotion regulation, RSA baseline and RSA reactivity in response to environmental demands (Beauchaine, 2001). Baseline/resting RSA reflects individual differences in capacities to focus attention, regulate emotions, and maintain homeostasis (Porges, 2007). High baseline RSA is associated with autonomic flexibility and adaptive emotion regulation in both children and adults across substantial literature (Balzarotti et al., 2017; Crowell et al., 2005). RSA reactivity often includes RSA suppression and RSA augmentation or recovery. The existing evidence concerning the developmental implications of RSA reactivity is still inconsistent, and whether RSA suppression is adaptive largely depends on the emotion-induction tasks as well as the risk levels of the participants. RSA suppression may reflect the reactivity of the PNS in response to environmental stress. Temporary suppression has been found to be an adaptive response to challenges and is associated with effective social functioning and emotion regulation (Graziano & Derefinko, 2013). It is often followed by RSA recovery, which reflects vagal regulation when the stress is removed. In contrast to RSA suppression, which appears to reflect individuals’ readiness to react to stress or challenges, RSA augmentation has been observed in response to social interactions and social engagement behaviors (Butler et al., 2006). High levels of RSA may reflect vagal regulation to facilitate attention and self-regulation to maintain internal equilibrium (Cui et al., 2015). Therefore, adaptive RSA reactivity may depend on the context, in other words, the specific challenge-task in which the RSA data are collected.

Parent-Child Physiological Synchrony and Its Developmental Significance

Children's adaptation to environmental circumstances requires emotional and behavioral self-regulatory skills. Children acquire those sophisticated skills through interacting with external environments, and parents play a central role in modeling emotion expression and facilitating the development of self-regulation throughout development (Eisenberg et al., 2010; Morris et al., 2007). Parents serve the external regulatory function via attuned, contingent responses to children's emotional cues and associated physiology. Meanwhile, children adjust to parents' behavioral and physiological responses, which provides an opportunity to practice self-regulation (Bell, 2020). Children gradually internalize regulatory skills from these moment-to-moment interactions with repeated experiences (Calkins, 2011), and the skills can be later applied to other situations and contexts. This dyadic process has been conceptualized as parent-child synchrony/co-regulation, and it has been found to lay the groundwork for children to learn to regulate their physiology, behaviors, and emotions; these self-regulatory skills may protect children from developing maladaptive outcomes (Feldman, 2007; Suveg et al., 2019). Synchrony and coregulation will be used interchangeably in this dissertation, with synchrony (covariation of autonomic physiology over time) serving as an index of parent-child co-regulation.

The bio-behavioral synchrony model posits that parent-child coordinated *behavioral* and *physiological* responses are essential in forming bond and attachment relationships (Feldman, 2012). Behavioral co-regulation refers to instantaneous and mutual coordination of observed behavioral exchanges between parent and child, such as mutual gazing and shared laughs. A body of studies has investigated the developmental implications of nonverbal and behavioral synchrony between parents and young children (Feldman, 2003; Davis et al., 2017), and the majority of these studies found that dyadic temporal coordination of relational behaviors (e.g., joint attention and shared affect) contribute to children's development of self-regulation and positive socio-emotional outcomes (Harrist & Waugh, 2002; Leclère et al., 2014). For example, parent-child affective contingency/predictability during positive and neutral interaction tasks was linked to higher levels of child self-regulation (Lobo & Lunkenheimer, 2020). A study with children who were exposed to war-related trauma found that among those children with PTSD, mother-child dyads showed lower sensitivity/reciprocity compared to those dyads with children who did not develop PTSD (Feldman & Vengrober, 2011).

In recent years, growing attention has been paid to the dyadic processes under the skin, i.e., physiological synchrony. Physiological synchrony has been conceptualized and operationalized in various ways (see Provenzi et al., 2018 for a review); we adopt the definition proposed in a recently published systematic review: "the dynamic, within-dyad coordination of physiological activity over time between two individuals that is directly tied to an interpersonal process" (DePasquale, 2020). The bulk of research on parent-child physiological synchrony has focused on dyadic, dynamic patterns of automatic synchrony, especially parasympathetic synchrony indexed by RSA.

Although parent-child behavioral synchrony is generally found to be associated with positive outcomes in children and behavioral synchrony is linked to greater physiological synchrony, the developmental implications of physiological synchrony are still unclear. In a normative community sample, Lunkenheimer et al. (2015) found that positive synchrony (related patterns of real-time RSA increases and decreases) in RSA between mothers and preschoolers was associated with children's positive functioning. Negative synchrony (e.g., inverse patterns of real-time RSA increases and decreases within-dyad) was evident in dyads with children exhibiting higher levels of externalizing problems. Results suggested that parasympathetic synchrony was indicative of adaptive interpersonal processes in low-risk families. Conversely, in another study involving both clinical (i.e., with clinical levels of externalizing problems) and non-clinical samples, Woltering et al. (2015) found that patterns in heart rate synchrony in clinical dyads was not different from the non-clinical dyads. Combining both clinical and nonclinical dyads, those with higher physiological synchrony showed higher levels of repair (i.e., recovery from a negative event) following a contentious discussion, which was also associated with more attunement behaviors (e.g., joint attention and reciprocity). The findings imply that although positive synchrony in heart rate is associated with positive behavioral interactions, physiological synchrony was not found to be significantly different between children with higher and lower behavioral problems.

Existing evidence suggests that the presence of positive physiological synchrony in parent-child interactions and its developmental significance are dependent upon the nature of context, specifically, the characteristics of the interactional tasks, risk conditions, and psychopathology of parent and child (see DePasquale, 2020 for a review).

Parasympathetic synchrony appeared to be weaker during structured teaching tasks, compared to those less structured tasks (i.e., free play and cleanup) in mothers and preschoolers (Lunkenheimer, Tiberio et al., 2018). Another study with preadolescents showed that tasks that required the greatest interaction (i.e., conflict discussion task) revealed the strongest dyadic synchrony. Also, synchrony was found to be weaker when mothers were less engaged in tasks (Skoranski et al., 2017).

Intervention Effect on Synchrony

After Deployment, Adaptive Parenting Tools (ADAPT; Gewirtz et al. 2018b) is a group-based preventive intervention for post-deployed military families. ADAPT is an adaptation of the Parent Management Training–Oregon model (PMTO; Forgatch & Gewirtz, 2017), which teaches parents to reduce coercive parenting and promote positive parenting. Mindfulness and emotion coaching components were added to the standard PMTO to strengthen parents' emotion regulation and emotion socialization skills (Gewirtz et al. 2014). Prior studies revealed effects of ADAPT on parenting and child adjustment, including decreases in parental nonsupportive emotion socialization behaviors and child adjustment problems, and increases in parental positive engagement (Gewirtz et al., 2018b; Zhang et al., 2018). However, previous findings focused more on mean level changes in parenting and child behaviors over longer time scales (e.g., months, years). Less is known about the dynamic processes that occur during moment-to-moment parent-child interactions, and whether the parenting intervention affected these processes.

Changing patterns of parent–child coregulation may act as markers of treatment effectiveness in evidence-based family interventions (Granic et al., 2007). Parent-child moment-to-moment emotional dynamics (indexed by physiological synchrony) could potentially be regarded as an important intervention outcome. Given that children's self-regulation development is shaped through moment-to-moment interactions with primary caregivers, it is critical to include and examine real-time emotional dynamics in parent-child interactions as a key outcome of parenting interventions.

Research Gaps and General Research Questions

Although parent-child behavioral synchrony has been consistently found to be associated with positive child functioning, the relationship between physiological synchrony and child self-regulation is yet to be elucidated. A growing body of research has examined the role of interaction tasks, child and parent characteristics, and family risk status in shaping the presence and/or magnitude of physiological synchrony, but what is missing is the direct association between physiological synchrony and child self-regulatory processes. Besides, no study to date has examined parent-child physiological synchrony in an at-risk (post deployment) military family sample. Finally, it is unknown if the ADAPT parenting intervention could improve parent-child physiological synchrony, which may, in turn, be associated with child socio-emotional adjustment.

This dissertation comprises two studies to address the existing research gaps. Study 1 will examine the relationship between mother-child physiological synchrony and child self-regulation in post-deployed military families. Additionally, the associations of synchrony with child age, parental emotion regulation, and parenting will be tested. Study 2 will examine the impact of the ADAPT parenting program on mother-child physiological synchrony. Whether physiological synchrony moderates the intervention effects on emotion-related parenting and child self-regulation will also be explored. Due to prior findings suggesting greater synchrony may be observed in tasks with greater engagement and structure, this dissertation will focus on a mother-child problem-solving task.

Study 1: Mother-Child Physiological Synchrony and its Relationship with Child Self-Regulation and Parenting Behaviors

The Dynamic and Dyadic Nature of Emotion Regulation

Emotion regulation ebbs and flows in response to an individual's goals. In other words, emotion-related physiological processes and internal feelings states are modulated moment by moment (Eisenberg & Morris, 2002). The dynamic nature of emotion regulation highlights temporal regulatory and appraisal processes (Cole et al., 2004; Thompson, 1994). In addition, emotion regulation is developed through and affected by social interactions. The bidirectional linkage of oscillating emotional channels between two entities characterizes the process of co-regulation (Butler & Randall, 2013). Guided by dynamic systems theory (Thelen & Smith, 1994), the dynamic and dyadic features of emotion regulation are summarized in the Temporal Interpersonal Emotion System (TIES) model (Butler et al., 2011). The key of the TIES model is that the temporal flow of the subcomponents of emotion (experience, expressive behavior, physiology, etc.) in one person is connected directly to a parallel stream of emotional components in another person or persons. Therefore, parent-child phycological co-regulation is an application of the TIES model in the context of parent-child interactions by focusing on the coupling of physiological responses.

Physiological Synchrony and Child Self-Regulation and Psychosocial Adjustment

Positive synchrony appears to be found in non-maltreating dyads compared with synchrony patterns of children and their maltreating parents, which suggests the adaptive function of positive synchrony. Lunkenheimer, Busuito et al. (2018) found positive synchrony in RSA in both non-maltreating dyads and physically abusive dyads but no synchrony in neglectful dyads. At high maltreatment severity, both abusive and neglectful dyads showed negative synchrony. In another study, the same group of authors found negative synchrony in maltreating families with higher levels of child-initiated repair (Lunkenheimer et al., 2019). In addition, abusive and neglected mothers were found to show different patterns of concurrent and lagged relationships between parenting and RSA over the course of a joint task with their children (Skowron et al., 2013). Existing evidence suggests negative synchrony in maltreating dyads, but the dynamic process may be altered by maltreatment subtype and severity. In contrast, positive synchrony has also been found to be linked to maladaptive outcomes. Ahemaitijiang and colleagues (2020) found that parental psychological control and emotion dysregulation was only found to be significantly associated with child aggressive behaviors among children who showed positive physiological synchrony (moment-to-moment matching of inter-beat intervals/IBI) with their parents. It appears that positive physiological synchrony may place children at greater risks for maladaptive adjustment in the face of negative parenting.

In summary, the developmental implications of parent-child physiological synchrony appear to be context-dependent, and physiological synchrony may be affected by a range of factors, such as characteristics of the interactional tasks, child psychopathology, parental psychopathology and emotion regulation, parenting, and family-level risks. As discussed in the general introduction, the impact of the characteristics of the interaction task has been relatively well-studied (Lunkenheimer, Tiberio et al., 2018; Skoranski et al., 2017) and will not be the main focus of the current study. The impact of each of the rest factors is discussed below.

Child Psychopathology, Emotion Dysregulation, and Synchrony

Research investigating the role of child psychopathology and dysregulation found positive synchrony among caregivers and children exposed to trauma but with fewer PTSD symptoms (Gray, Lipschutz, & Scheeringa, 2018) and negative synchrony in dyads with children exhibiting higher levels of externalizing problems, lower levels of physiological regulation, and higher levels of internalizing problems (Lunkenheimer et al., 2021; Suveg et al., 2019). It appears that child behavioral problems and emotion dysregulation may disrupt the positive concordance in RSA between parents and children.

Family-Level Risk, Parent Mental Health, Emotion Regulation, and Synchrony

In addition to age differences, the dyadic physiological process also varies as a function of family-level risk conditions and parent characteristics (e.g., psychopathology and emotion dysregulation). In a sample of families with socioeconomic risks, Suveg and colleagues (2016) found that at high levels of family risk, positive behavioral synchrony and child self-regulation was higher when physiological synchrony was low. In other words, high family risk combined with higher physiological synchrony generated the poorest relational and developmental outcomes. Synchrony was also found to be stronger between insecure-resistant children and their mothers among the four attachment groups (i.e., secure, insecure-resistant, insecure-avoidant, and disorganized; Smith et al., 2016).

Several studies found negative synchrony in the context of higher maternal depression and positive synchrony in the context of lower maternal depression in both high-risk and clinical samples (Amole et al., 2017; Suveg et al., 2019; Woody et al., 2016). In addition, positive synchrony may exacerbate the link between maternal depression and child psychopathology symptoms. For example, West et al. (2019) found that the association between maternal depressive symptoms and child behavioral problems was stronger in those dyads that showed positive physiological synchrony vs. those that showed negative physiological synchrony. Moreover, the association between physiological synchrony and child adjustment outcomes may be moderated by parental emotion regulation. Creavy and colleagues (2020) found that negative synchrony was linked to higher child empathy in children with parents with lower emotional acceptance (i.e., poorer emotion regulation), but the association was not observed in dyads with parents having higher emotional acceptance. Also, maternal negative affect was found to attenuate the physiological linkage between mothers and adolescents, such that mother RSA was not found to be significant associated with subsequent child RSA when mothers exhibited more negative emotions (McKillop & Connell, 2018).

Parenting Behaviors and Synchrony

Research investigating the effect of parenting practices on parent-child physiological synchrony is scarce. Firm control parenting (i.e., strict discipline) was found to be associated with higher RSA synchrony among youths who showed higher galvanic skin response reactivity (higher levels of SNS activity in response to stress). Parental engagement also plays a role, such that maternal disengagement behaviors (e.g., ignore children's bids for attention) have been linked with negative physiological synchrony (Skoranski et al., 2017).

Taken together, although positive parent-child physiological synchrony underlies adaptive developmental outcomes in lower-risk samples, risk factors (both at family and individual levels) may interfere with this interpersonal process, either by contributing to divergence in the dyadic concordance (i.e., negative synchrony) or by modifying the association between synchrony and child regulatory outcomes (Davis et al., 2018).

Research Gaps

Much of the extant literature examining physiological synchrony has focused on infants, toddlers, and preschoolers. This is because children are actively modeling and internalizing self-regulation skills through social interactions during this period of life, and parents play important roles as external regulators (Calkins, 2011). Parental sensitivity and responsiveness, along with concordance of ongoing physiological responses, provide an avenue for children to develop attentional behaviors and modulate emotions (Bell, 2020). However, the development of self-regulation continues through middle childhood and preadolescence, and thus parent-child physiological synchrony remains significant during these stages. In fact, middle childhood and preadolescence represent a time of increasing autonomy and independence, leading to shifts in the nature of parent-child relationships. School-aged children show greater self-control and behavior regulation relative to younger children, and these regulation skills may contribute to their problem-solving strategies as they adapt to internal and external environments (Davies & Cummings, 2006). Children at this age spend less time with families compared to early childhood and develop more horizontal relationships with parents (Morris et al., 2017). Despite these transformations, the development of emotion regulation during this period of life is still greatly influenced by the family context and parents' behaviors such as emotion coaching and emotion modeling (Morris et al., 2007). Parenting behaviors also have an impact on children's autonomic nervous system development (see Propper & Holochwost, 2013 for a review). It is as yet unclear whether physiological synchrony plays a role in child self-regulation in middle childhood and whether child age would moderate this association.

In addition, although a body of research has revealed how physiological synchrony differs as a function of parent and child characteristics and family-level risks, a fundamental question still to be answered is whether and how physiological synchrony is directly associated with child self-regulation. It is critical to elucidate the developmental significance of physiological synchrony before moving forward to investigate the moderation effect of risk and protective factors.

The current study

This study sought to investigate the association between mother-child synchrony in RSA and child self-regulation in a sample of post-deployed military families with primarily school-aged children. Also, we examined whether physiological synchrony is associated with child age, parent emotion regulation, and parenting behaviors. A dyadic problem-solving task was used to assess RSA and compute RSA synchrony. To account for the dynamics of parenting across different interaction tasks, the micro-coding of parenting behaviors during the dyadic problem-solving task was used to assess parenting. We hypothesized that 1) mother-child synchrony in RSA would be positively associated with child emotion regulation and cognitive control; 2) dyads comprising mothers with younger (vs. older) children would show higher levels of positive synchrony; and 3) higher levels of parental emotion dysregulation and more negative parenting behaviors would be associated with higher levels of negative physiological synchrony or lower levels of positive synchrony.

Methods

Participants

The current study represents a secondary data analysis of the larger ADAPT study, which is a randomized controlled trial of a parenting program for military families that recruited 336 families with at least one deployed parent (i.e., 313 mothers, 294 fathers, and 336 children) from a Midwestern state. Families were eligible to participate in the ADAPT study if at least one parent had deployed to the post 9/11 conflicts (i.e., Operations Iraqi Freedom (OIF), Enduring Freedom (OEF), or New Dawn (OND)) and parents had at least one child between the ages of 4 and 13 living in the home. This study used a subsample of 108 mother-child dyads. These participants were selected because they had complete RSA data for both mother and child during a baseline reading task as well as the problem-solving task. 205 dyads were excluded because of the following reasons: 1) the family did not participate in-home assessments; 2) the family completed family interaction tasks in a classroom setting; 3) the family completed in-home assessments but the baseline reading task was not administered; 4) either mother or child refused to wear the IBI recording equipment or did not participate; 5) IBI data not recorded because of administrative error or equipment malfunctions; 6) the start time of IBI data recording or the problem-solving task was unavailable because of issues with video-recording; 7) raw IBI data of either mother or child contained excessive artifacts; 8) RSA data of either mother or child contained less than 5 segments. Detailed information on data collection and data cleaning are described in the procedure section. Of the 108 mother-child dyads, mothers reported a mean age of 35.79 years (*SD* = 5.65, range = 25 - 49), and 17 mothers (15.7%) were deployed. The majority identified as Caucasian/White (92.6%). The target children were on average 8.85 years (*SD* = 2.64, range = 4 - 14), with 60 boys (55.6%) and 48 girls (44.4%). Detailed demographic information is presented in Table 1. In addition, independent-sample t-tests and chi-square tests were conducted to test for differences between the included subsample and the remainder of the full sample on the key demographic variables, and the results are presented in Table 1.

Procedure

Participants were recruited through presentations at mandatory pre-deployment and reintegration events for all NG/R personnel, mailings from the Minneapolis Veterans Affairs Medical Center to all OIF/OEF veterans, flyers throughout the Minneapolis/St. Paul area, social media, and word of mouth. Interested families were directed to a brief online screener, where they completed the informed consent. Part of the initial online assessment was completed online, which included some self-report measures. After completion of the initial survey, research staff set up an in-home assessment, during which additional assessments (questionnaire and observational) were collected with the parent(s) and the target child. All study procedures were approved by the University of Minnesota's Institutional Review Board.

IBI data were recorded during in-home assessments, administered by 2-3 trained technicians. A Polar RS800CX (Polar Electro, US) heart rate monitor was used to assess IBIs at a sampling rate of 1000 Hz (a resolution of 1 ms for each inter-beat interval). This monitor provides a low-cost, wireless recording of IBI using electrodes attached to a chest strap fixed around the chest of the participant. The IBI data obtained using the Polar monitor has been validated in children and adults compared to data collected via electrocardiogram (ECG) devices (Gamelin et al., 2008; Nunan et al., 2009). Participants were instructed to put on the device and breath normally without moving excessively during recording. The heart rate was displayed on the watch screen and the IBI data were stored in the watch and transferred to a computer later on. Families were guided to engage in a series of structured family interaction tasks (dyadic tasks and triadic tasks) while wearing the Polar device, and the entire process of the interaction was videotaped and later time-stamped in BORIS software (Friard et al., 2016) to match with the IBI series.

This study used the data collected during the reading baseline task and the mother-child dyadic problem-solving task. In the reading task, both father and mother were instructed to read a neutral story to the child while the child was sitting and listening. In the dyadic problem-solving task, the mother was presented with a list of common family conflicts (e.g. tidying room, playing music loudly, etc.). She first rated the degree to which each issue had been a "hot topic" in the family in two weeks on a 4-point scale (0 = Irrelevant, 1 = Not at all "hot", 2 = "Hot", 3 = "Boiling hot") on a list of family issues and then selected the hottest issue which was discussed during the dyadic task with their child. Dyads were asked to discuss this issue and try to solve it within 5 minutes.

The IBI data were processed using the following steps to obtain RSA data. First, the raw IBI data were segmented in CardioSegmenter (Brain-Body Center for Psychophysiology and Bioengineering, University of North Carolina, Chapel Hill, 2020) using the timestamps coded in BORIS. Second, the segmented IBI data were manually cleaned using CardioEdit (Brain Body Center, University of Illinois at Chicago, 2007) when artifacts were detected and removed (correction methods included interior division, summation, and a combination of each). The whole segment of data was regarded as unusable if more than 5% of artifacts were detected. The IBIs of 20% of participants were edited by a second research assistant for a reliability check. Third, RSA was quantified using the Porges–Bohrer method (Porges & Bohre, 1990), which was conducted using CardioBatch Plus (Brain-Body Center for Psychophysiology and Bioengineering, University of North Carolina, Chapel Hill, 2016) with cleaned IBI data. CardioBatch Plus provides age-specific parameters for estimating the amplitude of RSA for infants (0-2 years), children (3-6 years), adolescents (7-17 years), and adults (12+ years). RSA was quantified as a natural logarithm ($\ln(ms^2)$) of the variance in the heart period pattern associated with spontaneous respiration (0.12–0.40Hz in adults and 0.24–1.04 Hz in children). Because most children were above 7 years (65.7%), the adolescent parameters were used to analyze RSA data for all children in this study for the purpose of consistency across individuals. Mean RSA magnitude was estimated for each 30-s epochs.

Measures

Child Self-Regulation. Child self-regulation was measured with the parent version and the teacher version of the Behavioral Assessment Scale for Children-Second Edition (BASC-2-PRS and BASC-2-TRS; Reynolds & Kamphaus, 2004) reported by both parents. Anger Control, Emotional Self-Control, and Executive functioning were included in the BASC-2 PRS and BASC-2-TRS as content scales. Parents/teachers were asked to rate the frequency of children's behaviors on a Likert scale from 0 (*never*) to 3 (*almost always*). The Anger Control scale reflects "the tendency to become irritated and angry quickly and impulsively, coupled with an inability to regulate affect and control during such periods”. This scale includes 9 items (e.g., “Hits other children”, “Threatens to hurt others”, “Argues when denied own way”). The Emotional Self-Control scale reflects “the ability to regulate one’s affect and emotions in response to environmental changes”. This scale includes 6 items (e.g., “Loses temper too easily”, “Has poor self-control”, “Is easily upset”). The Executive Functioning scale reflects “the ability to control behavior by planning, anticipating, inhibiting, maintaining goal-directed activity, and reacting appropriately to environmental feedback in a purposeful, meaningful way”. This scale includes 10 items (e.g., “Is easily distracted”, “Acts without thinking”, “Is a ‘self-starter’”). T-scores were computed and used in the current analysis. These scales were only available for children above age 6, therefore, data for children below age 6 (n = 21) were missing. Mean scores of father reports and mother reports were computed and used in the final analyses. The three subscales demonstrated adequate reliability in this sample with Cronbach’s αs were mostly above 0.7 (Anger Control: $\alpha = .667$ in father reports, $\alpha = .640$ in mother reports, $\alpha = .764$ in teacher reports; Emotional Control: $\alpha = .809$ in father reports, $\alpha = .832$ in mother reports, $\alpha = .827$ in teacher reports; Executive Functioning: $\alpha = .756$ in father reports, $\alpha = .777$ in mother reports, $\alpha = .859$ in teacher reports).

Parental Emotion Regulation Difficulties. The Difficulties in Emotion Regulation Scale (DERS, Gratz & Roemer, 2004) is a 36-item self-report scale assessing individuals’ responses to negative emotional experiences. Participants were asked to rate on a 1 to 5 scale (1 = *almost never*, 5 = *almost always*) their emotion regulation difficulties in six domains/subscales: nonacceptance (e.g., “When I’m upset, I feel like I am weak.”), difficulty engaging in goal-directed behaviors (e.g., “When I’m upset, I have difficulty getting work done."), impulse control difficulties (e.g., "When I'm upset, I become out of control."), lack of awareness (e.g., "When I'm upset, I acknowledge my emotions."), limited strategies (e.g., "When I'm upset, it takes me a long time to feel better."), and lack of clarity (e.g., "I am confused about how I feel.") at baseline and 1-year follow-up. This scale has shown adequate construct and predictive validity (Gratz & Roemer, 2004). A total score was computed such that higher scores indicated more emotion regulation difficulties. The Cronbach's α in this sample was .769 at baseline.

Parenting Behaviors. Each mother's behaviors were coded using the microsocial Relationship Affect Coding System (RACS; Peterson et al., 2010; Snyder et al., 2016) during the dyadic problem-solving task. The RACS contains three categories of behaviors: verbal, physical, and affect. Mothers' behaviors were coded in real-time, and these categories were coded in a mutually exclusive and exhaustive manner, such that each mother had one verbal, one physical, and one affect code at a given moment of the interaction. Verbal codes included positive verbal, talk, negative verbal, positive structure, directive, and negative directive. Physical codes included positive physical, physical contact, and negative physical. Affect codes included anger/disgust, validation, distress, positive affect, and ignore. Four coders were trained until an inter-rater agreement $\kappa > .70$ was reached for all codes on a sample of six families (35 minutes for each family). Biweekly calibration meetings were held to minimize drift. The onset and offset of each code were recorded and summarized in terms of duration, duration proportion, and rate per minute. The rate per minute variables for each code was used in the current study. This study focused on six codes that are theoretically more closely related to child socioemotional development. These codes are directive, negative directive, anger/disgust, positive affect, positive physical contact, and negative physical contact.

Directive behaviors are those commands or statements for behavior change, such as "Let's think of another solution." Negative directive behaviors reflect warnings or threats of unpleasant consequences, such as "You watch your step or else." Anger/disgust includes raised voice, irritation, constrained anger, physical cues, and contempt. Positive affect includes caring, smiling/laughter, enjoyment, general positive affect, unexpected news, and surprise. Positive physical contact is characterized as affectionate positive contact between two people, such as hugs, embraces, kisses, sitting with an arm around another person, massaging, patting on the back. Negative physical contact is characterized as intrusive physical contact with another person including light hitting, pinching, slapping, ear flicking, grabbing another's hand, kicking, or shove.

Parent and Child RSA. As described above, the 30-sec RSA data were derived for both mother and child during the reading baseline task and the problem-solving task. The average score across the 30-second epochs was calculated for the baseline task, while RSA data for each 30-second epoch during the problem-solving task was used to model the dynamic changes in RSA. On average, dyads had 9.57 epochs during the 5-minute task.

Covariates. Parental post-traumatic stress disorder (PTSD) symptoms were measured using the Post-Traumatic Stress Checklist, a self-report measure consisting of 17 items that assess PTSD symptoms in response to stressful military experiences. The PCL-Military version was administered to the deployed mothers (PCL-M; Weathers et al., 1994) while the civilian version was administered to the non-deployed mothers (PCL-C).

Other parent-related covariates include parent education, parent age, years of marriage, and household income. Years of marriage was the average of husband and wife reports of years married to the current spouse.

Data Analytical Strategy

Preliminary analyses, including running descriptive statistics, conducting missing data analysis, testing the overall trend of RSA trajectories across the problem-solving task, and plotting the dyadic RSA trajectories for each dyad were administered in R version 4.0.3 (R Core Team, 2020). Specifically, descriptive statistics and bivariate correlations were analyzed for study variables. Mean RSA scores across all epochs during the problem-solving task were created for both mother and child to present the average level of RSA. Little's Missing Completely at Random test (MCAR; Little & Rubin, 1989) was conducted with all observed variables. The test revealed that data were not missing at random, X^2 (78) = 105.71, p = .020. This was unsurprising due to the fact that missingness on self-regulation measures was dependent on child age. The Little's test was no longer significant after removing the three self-regulation variables, X^2 (46) = 39.33, p = .746. The lmer package in R (Bates et al., 2015) was used to run random intercept and random slope multilevel models for mother and child separately to estimate the overall trend across time.

The main hypotheses regarding the dynamics of mother-child RSA synchrony were estimated using the multilevel growth curve model in M*plus* 8.3 (Muthén & Muthén, 1998-2017). The maximum likelihood estimation with robust standard errors was used as the estimator. The mother model and child model were run separately to account for potential differences in intraindividual RSA trajectory and dyadic RSA synchrony. In both mother and child models, the concurrent synchrony was estimated as well as the lagged synchrony. *Concurrent synchrony* was estimated using the effect of mothers' RSA on children's RSA in the child model and the effect of children's RSA on mothers' RSA in the mother model for each dyad. *Lagged synchrony* was estimated using the effect of mothers' previous RSA on children's current RSA in the child model and the effect of children's previous RSA on mothers' current RSA in the mother model for each dyad. The autoregressive effect of children's previous RSA on children's current RSA in the child model and the autoregressive effect of mothers' previous RSA on mothers' current RSA in the mother model were controlled for at the within-dyad level. Both mother and child concurrent and lagged RSA were group-mean centered (relative to their corresponding average RSA during the problem-solving task) to eliminate the impact of task average RSA.

Concurrent Synchrony. The positive concurrent synchrony coefficient represents a consistent pattern of changes between mother and child, such that they both show increases or decreases at a given time. Whereas negative concurrent synchrony represents an opposite direction of changes between mother and child, such that one increases while the other decreases at a given time. Using the multilevel growth curve modeling approach, Level 1 (within-dyad level) estimated the within-dyad association. As is shown in equation 1.1.1 and equation 1.1.2, $mRSA_{i,t}$ and $cRSA_{i,t}$ denote the parent and child's RSA values respectively in dyad i, at time t. Individual's concurrent RSA was a function of an intercept for dyad i (modeled via $\beta 0_{Mi}$ or $\beta 0_{Ci}$), a slope representing parent-child concurrent synchrony (modeled via $\beta 1_{Mi,t}$ or $\beta 1_{Ci,t}$), a slope representing trend across time (modeled via $\beta 2_{Mi,t}$ or $\beta 2_{Ci,t}$), and a residual within-dyad error term (modeled via $\varepsilon_{Mi,t}$ or $\varepsilon_{Ci,t}$). The linear trend in RSA (i.e., child RSA or mother RSA) was removed such that time was controlled on level 1 with the first segmented in the problem-solving task set as 0. This was because intraindividual trends in RSA may confound the estimate for dyadic synchrony in RSA. In other words, synchronous patterns may be observed simply because dyads show similar patterns of changes across time (i.e., trend synchrony). Therefore, detrending has been recommended while testing concurrent or lagged synchrony (Helm et al., 2018).

Level 2 (between-dyad level) modeled the between-dyad variability in the Level 1 intercepts and slopes (see equation 1.2.1-1.2.3). Both the intercept and slopes were modeled as random across dyads. To test the association between synchrony and child self-regulation, child self-regulation variables (i.e., anger control, emotion control, and executive functioning) were entered as between-level variables. The covariation between the random slopes representing concurrent synchrony and the three self-regulation variables were estimated separately. To test the effect of child age, the intercept and slopes on Level 1 were modeled as a function of the average intercept/slope (γ_{M00}, γ_{M10}, and γ_{M20}), the effect of child age (γ_{M01} and γ_{M11}), and the residual error term (μ_{M0i} and μ_{M1i}). The same steps applied to the investigation of the effects of parenting behaviors and parental emotion regulation as between-level variables. The covariates were controlled for on level 2, but for the sake of simplicity, the parameters were not denoted in equation 2.

Level 1 (within-dyad):

$$mRSA_{i,t} = \beta 0_{Mi} + \beta 1_{Mi,t} cRSA_{i,t} + \beta 2_{Mi,t} Time + \varepsilon_{Mi,t} \quad (1.1.1)$$

$$cRSA_{i,t} = \beta 0_{Ci} + \beta 1_{Ci,t} mRSA_{i,t} + \beta 2_{Ci,t} Time + \varepsilon_{Ci,t} \quad (1.1.2)$$

Level 2 (between-dyad, same for the child model):

$$\beta 0_{Mi} = \gamma_{M00} + \gamma_{M01} CAge + \mu_{M0i} \quad (1.2.1)$$

$$\beta 1_{Mi,t} = \gamma_{M10} + \gamma_{M11} CAge + \mu_{M1i} \quad (1.2.2)$$

$$\beta 2_{Mi,t} = \gamma_{M20} \quad (1.2.3)$$

Lagged Synchrony. The positive lagged synchrony coefficient represents a consistent pattern of changes between one's concurrent RSA and the other's previous RSA and the negative lagged synchrony represents one's concurrent RSA and the other's previous RSA change in opposite directions. Similar to the models examining concurrent synchrony, Level 1 (within-dyad level) estimated the within-dyad association. As is shown in equation 2.1.1 and equation 2.1.2, $mRSA_{i,t}$ and $cRSA_{i,t}$ denote the parent and child's RSA values respectively in dyad i, at time t. Individual's concurrent RSA was a function of an intercept for dyad i (modeled via $\beta 0_{Mi}$ or $\beta 0_{Ci}$), a slope representing parent-child lagged synchrony (modeled via $\beta 1_{Mi,t}$ or $\beta 1_{Ci,t}$), a slope representing the autoregressive effect of an individual's previous RSA (modeled via $\beta 2_{Mi,t}$ or $\beta 2_{Ci,t}$), a slope representing trend across time (modeled via $\beta 3_{Mi,t}$ or $\beta 3_{Ci,t}$), and a residual within-dyad error term (modeled via $\varepsilon_{Mi,t}$ or $\varepsilon_{Ci,t}$).

Level 2 (between-dyad level) modeled the between-dyad variability in the Level 1 intercept and slopes (see equation 2.2.1-2.2.4). Both the intercepts and slopes were modeled as random across dyads. Similar to the concurrent synchrony models, to test the effect of child age, the intercept and slopes on Level 1 were modeled as a function of the average intercept/slope (γ_{M00}, γ_{M10}, γ_{M20} and γ_{M30}), effect of child age (γ_{M01}, γ_{M11}, and γ_{M21}), and the residual error term (μ_{M0i}, μ_{M1i} and μ_{M2i}). The same steps applied to the investigation of the effects of parenting behaviors and parental emotion regulation as between-level variables.

Level 1 (within-dyad):

$$mRSA_{i,t} = \beta 0_{Mi} + \beta 1_{Mi,t} cRSA_{i,t-1} + \beta 2_{Mi,t} mRSA_{i,t-1} + \beta 3_{Mi,t} Time + \varepsilon_{Mi,t} \quad (2.1.1)$$

$$cRSA_{i,t} = \beta 0_{Ci} + \beta 1_{Ci,t} mRSA_{i,t-1} + \beta 2_{Ci,t} cRSA_{i,t-1} + \beta 3_{Ci,t} Time + \varepsilon_{Ci,t}$$

(2.1.2)

Level 2 (between-dyad, same for the child model):

$$\beta 0_{Mi} = \gamma_{M00} + \gamma_{M01} CAge + \mu_{M0i} \quad (2.2.1)$$

$$\beta 1_{Mi,t} = \gamma_{M10} + \gamma_{M11} CAge + \mu_{M1i} \quad (2.2.2)$$

$$\beta 2_{Mi,t} = \gamma_{M20} + \gamma_{M21} CAge + \mu_{M2i} \quad (2.2.3)$$

$$\beta 3_{Mi,t} = \gamma_{M30} \quad (2.2.4)$$

Results

Preliminary Analyses

Descriptive statistics and bivariate correlations are presented in Table 2. Resting RSA was positively associated with average RSA during the problem-solving task in both mothers (r = .88) and children (r = .80). Mothers' level of resting RSA was negatively associated with their emotion regulation difficulties (r = -.24), age (r = -.34), and year of marriage (r = -.26). Children's level of resting RSA was positively associated with their executive functioning (r = -.23). Children's average RSA during the problem-solving task was positively associated with anger control (r = -.22), emotional control (r = -.24), and executive functioning (r = -.27). In other words, higher levels of children's average task RSA were positively correlated with better self-regulation. Mothers' emotion regulation difficulties were positively correlated with poorer emotion control (r = .29) and poorer executive functioning (r = .23) in children, which suggested the association between maternal emotion regulation and child self-regulation. Mothers' emotion regulation difficulties were also positively associated with their PTSD symptoms (r = .48). Children's lack of anger control, lack of emotional control, and lack of executive functioning were positively associated with each other in both parent reports and teacher reports (rs = .80~.86). Parent reports on child self-regulation measures were positively and significantly correlated with teachers' reports (rs = .34~.53). Mothers' PTSD symptoms were also positively associated with lack of anger control (r = .23), lack of emotion control (r = .29), and lack of executive functioning (r = .33) in children. In terms of the correlations among the parenting behavior codes, mothers' directive behaviors were positively associated with positive physical behaviors (r = .29) and negative physical behaviors (r = .47). Mothers' negative directive behaviors were associated with more anger/disgust affect (r = .32). Mothers' positive physical behaviors were associated with more negative physical behaviors (r = .35). Mothers' displays of anger/disgust were associated with more positive affect (r = .27). These results are seemingly contradictory but in essence, in line with the nature of the micro-social codes because mothers with higher levels of emotion expression may show higher rates of both positive affect and negative affect during the same task.

The demographic comparison between the subsample included in the current study and the remainder in the full sample showed that mothers included in this sample were not significantly different from the rest of the sample. However, children in this sample were significantly older than the rest of the sample ($t(334) = -2.35, p < .05$), and proportionally more boys were included in this subsample ($X^2(1, N = 336) = 5.33, p < .05$). Thus, child gender and age were controlled in the following analyses.

Tests of the overall trend of mother and child RSA showed that a linear decrease (RSA withdrawal) was observed in mother data, $b = -.02$, $t(99) = -2.24$, $p = .028$, but the same trend was not found in child RSA, $b = -.01$, $t(105) = -1.41$, $p = .163$. Nevertheless, both mothers' and children's RSA were detrended in the following analyses to prevent confounding effects of trend synchrony (Helm et al., 2018). RSA trajectories during the problem-solving task across all epochs for mother and child are shown in Figure 1. In addition, the mean RSA magnitude for each epoch is reported in Table 3.

Primary Analyses

The null models examining concurrent synchrony and lagged synchrony were first established for mother and child separately. No between-level covariates were added at this time. *Concurrent synchrony* was first estimated. As shown in Table 4, at the within-dyad level, the linear trend was significant in the mother model ($b = -.02, p = .024$) but not the child model ($b = -.02, p = .106$). The residual variance in both models was found to be significant ($\sigma^2 = .30, p < .001$ in the mother model and $\sigma^2 = .35, p < .001$ in the child model). At the between-dyad level, no significant intercept for the synchrony coefficient was found in either mother (*b* = -.04, *p* = .123) or child model (*b* = -.06, *p* = .084), indicating no presence of concurrent synchrony on average for the entire sample. Then, *lagged synchrony* was estimated. As shown in Table 4, at the within-dyad level, the linear trend was significant in the mother model (*b* = -.03, *p* = .001) but not in the child model (*b* = -.02, *p* = .109). The residual variance in both models was found to be significant (σ^2 = .26, *p* < .001 in both mother and σ^2 = .31, *p* < .001 child models). At the between-dyad level, no significant intercept for the lagged synchrony coefficient was found in either mother (*b* = -.01, *p* = .806) or child model (*b* = -.07, *p* = .139), indicating no presence of lagged synchrony on average for the sample.

RSA Synchrony and Child Self-Regulation

The association between RSA synchrony (concurrent and lagged) and child self-regulation (parent-reported and teacher-reported) was estimated via the covariation of the synchrony coefficient and child self-regulation at the between-dyad level. Child age, child gender, mother age, maternal PTSD symptoms, maternal education level, and household income were controlled for at the between-dyad level. Maternal PTSD symptoms were not significantly predictive of either concurrent synchrony or lagged synchrony in either model.

Table 5 presented the results for each self-regulation measure (i.e., lack of anger control, lack of emotion control, and lack of executive functioning). In the child model, parent-child lagged synchrony was found to be negatively associated with parent-reported anger control, parent-reported executive functioning, teacher-reported anger control, teacher-reported emotion control, and teacher-reported executive functioning. See Figure 3 for the sample scatterplot between lagged synchrony in the child model and child lack of executive functioning (parent-reported). However, neither concurrent synchrony nor lagged synchrony was found to be associated with child self-regulation in the parent model.

It was noteworthy that dyadic synchrony was indicated by the random slopes, and it may vary from positive values to negative values although the intercept was negative and nonsignificant. The positive association between lagged synchrony and child self-regulation in the child model suggested that positive lagged synchrony (i.e., the magnitude of increase or decrease in children's RSA relative to individual average follows the increase or decrease in mothers' RSA in the same direction) was linked to higher levels of self-regulation whereas negative lagged synchrony (i.e., the magnitude of increase or decrease in children's RSA relative to individual average follows the increase or decrease in mothers' RSA in the opposite direction) was linked to lower levels of self-regulation.

The Impact of Child Age

Child age was added to the null models as a between-dyad level variable to predict concurrent synchrony and lagged synchrony. In child model, child age was not found to be significantly associated with concurrent synchrony (b = -.02, p = .094), but age was negatively associated with lagged synchrony (b = -.04, p = .013; See Figure 4 for the scatterplot). In mother model, child age was not significantly associated with neither concurrent synchrony (b = -.02, p = .074) or lagged synchrony (b = -.02, p = .286). A post-hoc analysis was conducted to examine whether child age moderates the association between lagged synchrony and child self-regulation in the child model (found significant in previous analyses), but no significant moderation effects were found.

The Impact of Parenting Behaviors and Parental Emotion Regulation

Maternal difficulties in emotion regulation was first added to the null models as a between-dyad level variable to predict concurrent synchrony and lagged synchrony. Child age, child gender, mother age, maternal PTSD symptoms, maternal education level, and household income were controlled for at the between-dyad level. In the child model, mother difficulties in emotion regulation was significantly associated with lagged synchrony (b = .01, p = .021) but not concurrent synchrony (b = .00, p = .996). The result suggested mother-child dyads were more likely to show positive lagged synchrony in mothers with more emotion regulation difficulties. In mother model, mother difficulties in emotion regulation was not significantly associated with either concurrent synchrony (b = .00, p = .717) or lagged synchrony (b = .00, p = .293).

The six codes of parenting behaviors were each added to the null models with the same set of covariates controlled for at the between-dyad level. Due to the large number of effects tested in this step, only significant results were reported here. Please see Table 6 for the statistics for each coefficient. In the child model, only the association between maternal negative directive and lagged synchrony was found (b = -2.45, p = .002), such that dyads were more likely to show negative lagged synchrony when mothers showed more negative directive behaviors. In the mother model, mothers' display of anger/disgust was associated with lower lagged synchrony (b = -.11, p = .007). Mothers' positive physical behaviors were associated with higher lagged synchrony (b = .19, p = .051). These effects suggested that dyads were more likely to show positive lagged synchrony when mothers showed more positive physical behaviors or less negative affect (i.e., anger/disgust). However, mothers' display of positive affect was also negatively associated with lagged synchrony (*b* = -.05, *p* = .040) such that dyads were more likely to show negative lagged synchrony when mothers displayed more positive affect.

Post-hoc Analysis on Concurrent Synchrony

As shown above, the lagged synchrony, but not the concurrent synchrony, was found to be associated with better self-regulation in the child model. Due to the seemingly important role of child age on synchrony coefficients, the moderation effect of child age on the association between concurrent synchrony and child self-regulation was investigated in the child model. To reduce the complexity of the between-dyad level model, the factor scores of the random slope indicating concurrent synchrony was saved out as a between-level variable. The association between this factor score and child self-regulation and the moderation effect of child age were estimated using linear regression. The moderated effect was found to be significant in the model predicting parent-reported executive functioning (*b* = -11.73, *t* = -2.16, *p* = .034). The Johnson–Neyman approach was employed and the region of significance was plotted (Johnson & Fay, 1950) to show the association at the continuum of the moderator values (Figure 5). It appeared that concurrent synchrony was negatively associated with child lack of executive functioning for children aged 9 or above.

Discussion

To our best knowledge, this study is the first study investigating parent-child physiological synchrony in post-deployed military families. The overarching goal of this study was to better understand the developmental significance of parent-child RSA synchrony by testing the association between synchrony and child self-regulation. In addition, this study sought to examine the impact of child-and parent-related characteristics, such as child age, parental emotion regulation, parenting behaviors, on the synchrony pattern. The primary hypotheses were 1) mother-child RSA synchrony would be positively associated with child emotion regulation and cognitive control; 2) mothers with younger children may show higher levels of positive synchrony; 3) maternal emotion dysregulation and negative parenting behaviors (or lack of positive parenting behaviors) would disrupt the positive synchrony pattern or would be associated with negative synchrony pattern. Four types of epoch-by-epoch synchrony were estimated using the multilevel growth curve modeling: child-to-mother concurrent synchrony and child-to-mother lagged synchrony in mother models and mother-to-child concurrent synchrony and mother-to-child lagged synchrony in child models.

Synchrony and Child Self-Regulation

The first hypothesis was partially supported as both mother-to-child concurrent synchrony and mother-to-child lagged synchrony in child models are associated with better child emotional regulation and cognitive control. These effects are reflective of mother-driven effects, such that child RSA changes corresponding to mother RSA changes in a concurrent or lagged manner. Although a causal relationship could not be drawn, these findings suggested the adaptive function of synchrony in that children's parasympathetic concordance with parents is linked to better self-regulation. The result is in line with the biobehavioral synchrony theory (Feldman, 2012) and empirical studies with infants, preschoolers, and adolescents (Feldman et al., 2011; Lunkenheimer et al., 2015; Woody et al., 2016). Surprisingly, no relationship between synchrony (i.e., child-to-mother concurrent synchrony and child-to-mother lagged synchrony) and self-regulation was found in mother models. It may be that the issue discussed during the problem-solving task in this study was picked by the mother, and mothers were more likely to take the leader role and drive the flow of the discussion. This behavioral process may also manifest physiologically so that only mother-to-child effects, but not child-to-mother effects, were found in the investigation of dyadic synchrony. Another potential explanation is that most children in the current sample are in their middle-childhood or pre-adolescence, and they may have gained the regulatory capacity to be responsive to mothers' RSA reactivity in the concurrent or lagged manner. This discrepancy between mother-to-child effects and child-to-mother effects was not observed in previous studies, because the majority of previous studies examining physiological synchrony in middle-childhood adopted either the cross-correlation functions derived through the autoregressive integrated moving average (ARIMA) approach (Creavy et al., 2019; Han et al., 2019) without accounting for the direction of the effects or the multilevel model approaching with only the mother-to-child effects tested (Suveg et al., 2019). Moreover, it is noteworthy that none of the fixed effects representing synchrony coefficients in the four types of epoch-by-epoch synchrony was statistically significant, which suggested that dyads did not exhibit positive/negative synchrony on the whole and may differ by context (Suveg et al., 2019; Lunkenheimer et al., 2020).

Child Age

The second hypothesis was partially supported in that the negative association between child age and lagged synchrony was found in the child model while the associations between child age and concurrent synchrony in both models were marginally significant. The findings collectively suggested that, in the current sample, younger children tended to show positive lagged synchrony with mothers while older children tended to show negative lagged synchrony. Although the role of child age has been recognized in prior literature, no distinctive pattern in the magnitude or direction of synchrony has been observed (see DePasquale, 2021 for a review). It may be because prior studies focused on a narrower age range or more homogeneous age groups, and the comparison between studies was not feasible due to different analytical strategies and levels of contextual risk across studies. This study included a sample of moderate size but with a relatively wider age range, which made it possible to examine the role of child age on dyadic synchrony. Consistent with our hypothesis, younger children (4-7 years) showed positive lagged synchrony such that child RSA matched the changes in the mother's RSA during the previous epoch. What was not hypothesized was that older children (8-13 years) showed discordant lagged synchrony (i.e., mother and child changed RSA in the opposite direction). Compared to children in middle childhood, preadolescents may have more inner resources to turn to when faced with external stress, and they may be less reliant on synchronous physiological reactivity with parents to regulate emotions and behaviors, therefore, showing less positive synchrony. However, it is still unclear why the divergent exchange was found in the majority of preadolescents and their mothers. As suggested in the current findings and previous studies (Woody et al., 2016) high levels of negative synchrony were linked to higher levels of negative affect in children and poorer self-regulation. Nevertheless, it is still unknown whether lagged synchrony has differential implications for child self-regulation in younger vs. older children due to nonsignificant moderation effects found in the post-hoc analyses.

In addition to the association between lagged synchrony and self-regulation, we also conducted post-hoc analyses examining the association between parent-child concurrent synchrony in the child model and child self-regulation, as well as the moderation effect of child age. Results showed that concurrent synchrony was significantly associated with executive functioning in children 9 years or above. The findings in part explained the lack of significant association between concurrent synchrony and child self-regulation, although the effect was only found for child executive functioning. It appears that, even though older children tend to show more negative concurrent synchrony with mothers, higher levels of negative concurrent synchrony (i.e., one's RSA increases while the other one's RSA decreases) were found in children with poorer executive functioning. However, this association was not found in children younger than 9 who tended to show positive synchrony or lack of synchrony (not positive nor negative).

This study adds to an emerging body of literature on parent-child physiological synchrony and the current findings raise critical questions regarding the interplay of synchrony, self-regulation, and child age. First, is synchrony a continuous construct ranging from negative values to positive values or a construct with two dimensions: direction and magnitude? If the former is true, what would be the threshold of determining significant positive/negative synchrony compared to lack of synchrony? If the latter is true, does positive synchrony have different developmental significance than negative synchrony? Synchrony was conceptualized as the "dynamic, within-dyad coordination of physiological activity over time" (DePasquale, 2021) in the current study, therefore it was operationalized as the strength/magnitude of linkage between parent and child in their RSA changes.

Second, is synchrony a state-level or trait-level measure? In other words, does parent-child synchrony fluctuate across tasks, days, months, or years, or it can serve as an indicator of one's responsiveness or sensitivity to the other's behavioral cues and physiological reactivity and may be stable in a given time frame? Ravindran et al. (2021) observed the dynamic changes in mother-child RSA synchrony along with dynamic changes in the intensity of negative emotional content in a film. Results showed that physiological concordance changed as a function of increases of intensity in environmental stimuli such that positive concordance was found when negative emotional content was increasing in the film. Although further studies are needed to replicate the results in tasks eliciting different types of emotions, Ravindran et al. (2021) suggested that physiological synchrony may be a state-level measure that may change in response to context and the characteristics of the dyads.

Third, what is the direction of the relationship between synchrony and child self-regulation? Parent-child synchrony has been theorized to lay the foundation for children to obtain self-regulation skills (Calkins, 2011), while child externalizing problems and self-regulation have also shown to affect synchrony (Lunkenheimer et al., 2015; 2020). It may be that consistent and positive synchrony could facilitate children's development of self-regulation in infancy and early childhood, and this positive synchrony pattern still holds in middle childhood and adolescence unless disrupted by parental psychopathology, child psychopathology, lack of engagement during the interaction, etc., (Amole et al., 2017; Motsan et al., 2021; Skoranski et al., 2017). Besides, a large number of other dispositional and contextual factors, including child genes, temperament, early childhood adversity, sibling relationship, family emotional climate, etc., may shape children's self-regulation. These factors, together with synchrony, may posit additive or interactive effects on child regulatory development across developmental stages.

Parental Emotion Regulation, Parenting Behaviors and Synchrony

The third hypothesis was also partially confirmed with contradictory findings observed. Mothers' emotion dysregulation was found to be associated with higher levels of mother-to-child lagged synchrony, i.e., higher levels of maternal emotion dysregulation strengthened the positive dyadic concordance such that child RSA was more likely to follow the changes in mother RSA in the same direction. Findings in terms of the association between parental psychopathology and synchrony were not significant in prior literature. Some studies showed negative synchrony or no synchrony in mothers with depression symptoms (McKillop & Connell, 2018; Suveg et al., 2019), whereas, some studies found higher synchrony in physiological arousal in dyads with more anxious parents (Smith et al., 2019). These discrepancies may be confounded by parental engagement in the task and parental behaviors (e.g., emotion expression). Parents with higher anxiety may engage in the tasks more than those with depressive symptoms or express more positive/negative emotions, which may further link to different levels of synchrony.

Similarly, contradictory findings were observed in the relationship between parenting behaviors and synchrony. Consistent with prior literature, mother RSA reactivity was more likely to follow child RSA reactivity in a consistent direction when mother showed more positive physical behaviors and in an opposite direction when mother showed more anger/disgust. Child RSA reactivity was more likely to follow mother RSA reactivity in an opposite direction when the mother showed more negative directive behaviors. Surprisingly, mother RSA reactivity was more likely to follow child RSA reactivity in an opposite direction when the mother showed higher levels of positive affect. In a study with mother-infant dyads (Waters et al., 2017), it was found that mother-infant synchrony in sympathetic reactivity (preejection period/PEP) was stronger in infants with physical contact with their mothers (sitting on mothers' laps). It appears that physiological synchrony may be strengthened by positive physical contact. Besides, it was first observed in this study that negative verbal directions and expressions of negative emotions were associated with negative lagged synchrony. However, the results with maternal positive affect do not seem to make sense in that the expression of positive affect is theoretically associated with higher levels of bio-behavioral synchrony. Because child behaviors were not observed during these interaction tasks, expression of positive affect may not necessarily be indicative of positive parenting. Future studies may code real-time child behaviors along with the RSA recording to uncover the function of the RSA synchrony in the moment.

Strengths

This study has several notable strengths. First, the sample has unique characteristics in that at least one parent in these family have been deployed overseas and may suffer from trauma-related symptoms. Children in the sample ranged from 4 years to 13 years, which allowed for the exploration of the role of child age on synchrony. Therefore, this study has important implications for research on physiological synchrony in at-risk families with children having a wide age range from preschoolers to adolescents. Second, this study employed a multilevel growth curve modeling approach and examined both concurrent and lagged synchrony in the mother model and child model. The discrepancy observed in these models may inform future investigations of the difference between parent-driven effects and child-driven effects. In addition, this study took into account the impact of parenting and parental emotion regulation. Of note, parenting behaviors were observed during the interaction task when RSA data were collected, which may be more representative of real-time parenting behaviors than a general measurement of parenting across contexts.

Limitations and Future Directions

In the meantime, this study has notable limitations. First, mean RSA values for each 30-s epoch were used in the analyses, therefore, the 1-epoch lagged effects reflected a 30-s lag. However. the 30-s window may average out significant signals about constantly changing parasympathetic nervous activities. Abney et al. (under review) found that 15-to 20-s windows seem to be as good as longer timescale windows to calculate RSA, which offers a way to better capture the dynamic changes in RSA in a shorter timescale. Creavy et al. (2019) employed a second-to-second approach to computing RSA as a continuous time series. These advanced methods to compute RSA would also provide a more valid indicator of RSA synchrony (Gates et al., 2015). Moreover, the meaningful interval length in which dyadic synchrony can be detected and whether the length differs across contexts is as yet unknown. Future studies should investigate the appropriate length of intervals as well as the lag time for observing concurrent and lagged synchrony. Second, we cannot draw conclusions about causality regarding the association between synchrony and self-regulation. Longitudinal studies are needed, after taking into account the developmental trajectories of child resting RSA and RSA reactivity (Perry et al., 2013), to address the question regarding whether synchrony impacts the development of self-regulation. Also, although this study found the seemingly linear relationship between child age and lagged synchrony, the developmental changes in synchrony are still unknown and need future longitudinal studies. Third, we regarded synchrony as a continuous construct without a clear distinction between co-regulation and co-dysregulation/positive synchrony and negative synchrony (Abney et al., under review). This raised critical questions about whether positive and negative synchrony have distinctive implications or whether synchrony is a continuous construct and ranges from negative values to positive values at each given time. It may be that both positive synchrony and lack of synchrony have equivalent effects on child outcomes, and what signifies negative development outcomes is negative synchrony or disorganized concordance. It is also possible that, as Harrist and Waugh (2002) pointed out, synchrony may not be an all-or-none condition, rather, dyads are constantly approaching and moving away from synchrony throughout the interaction. Since synchrony constantly changes in response to external stimuli (Ravindran et al., 2021), answering these questions may require real-time observations of child stress responses and self-regulation behaviors to determine whether positive synchrony is linked to more adaptive responses to stress vs. negative synchrony. Fourth, this study did not take into account triadic synchrony. Indeed, most families in this sample participated in another problem-solving task when the mother, father, and child were present. However, due to the complexity of modeling triadic synchrony and lack of prior evidence suggesting the implications of triadic synchrony, it was not examined in the current study. Indeed, a body of research has examined the synchrony between father and child (Gordon & Feldman, 2008; Li et al., 2020a; 2020b; Lunkenheimer et al., 2021), but less is known about whether and how triadic synchrony plays a role. Future studies should extend the current findings in father samples and triadic interaction contexts. Finally, the moderation model conducted as a post-hoc analysis did not take into account the measurement error of the random slope indicating synchrony. Methodological advances are needed to model the moderation effect of the random slopes within a multilevel modeling framework.

Conclusions and Implications

Guided by the biobehavioral synchrony theory (Feldman, 2012), this study provided empirical evidence supporting the association between parent-child physiological synchrony and self-regulation. Extending previous findings on the moderators of synchrony, this study showed the role of child age, parental emotion regulation, and parenting behaviors in synchrony. Specifically, positive synchrony was more likely to be observed in dyads with younger children, or among mothers having more emotion regulation difficulties and more supportive parenting behaviors. A better understanding of the developmental significance of synchrony as well as moderation processes may inform future developmental and intervention studies aiming to enhance parent-child relationships and increase child self-regulation, especially in families with a greater risk of negative parenting and parental mental health problems.

Study 2: Impact of a Military Parenting Intervention on Parent-Child Physiological Synchrony: Evidence from a Randomized Controlled Trial

Nearly three million U.S. military personnel have been deployed to Iraq and Afghanistan since the American War on Terror was initiated (U.S. Department of Defense, 2019). Combat stress and adjustment difficulties related to deployment persist during reintegration and may present substantial challenges to children in military families (Khaylis et al., 2011). Although most military children are resilient, the wartime deployment of parents appears to be a significant stressor for school-aged children (Flake et al., 2009). Children with deployed parents exhibit more adjustment problems, such as conduct problems, anxiety, and depression, compared to their community counterparts (Chartrand et al, 2008; Khaylis et al., 2011; Mansfield et al., 2011). Compromised parenting has been identified as a key mediator in the detrimental impact of parental deployment and child maladaptive outcomes (Gewirtz et al., 2018a; Zhang, Palmer et al., 2020).

The ADAPT Program

Parenting is malleable, and parenting programs may particularly benefit those parents who have been exposed to traumatic stress and struggle with parenting difficulties. After Deployment, Adaptive Parenting Tools (ADAPT; Gewirtz et al. 2018b) is a parenting intervention for post-deployed military parents. ADAPT is a modification of the Parent Management Training – Oregon Model (PMTO; Forgatch & Patterson, 2010) which is based on social interaction learning theory (Patterson, 2005), and focuses on five core components of effective parenting behaviors: problem-solving, constructive discipline, positive involvement, skill encouragement, and monitoring. In addition to these five components, ADAPT includes additional core components: emotion socialization (via teaching emotion coaching) and emotion regulation (via teaching mindfulness skills) to enhance parents' emotion regulation and coaching of children's emotions. These two skills were added due to the body of literature showing that improving parents' capacity to manage their own emotions and constructively respond to children's emotions is key to addressing children's adjustment problems (Katz et al., 2012). Emotion socialization is also theoretically congruent with the social interaction learning model (Snyder et al., 2013).

The ADAPT program has been shown to improve effective parenting (e.g., problem-solving and encouragement) and emotion socialization behaviors (e.g., parents' supportive responsiveness to children's emotional needs) (Gewirtz et al., 2018b; Zhang et al., 2018). For example, Gewirtz and colleagues (2018b) reported significant intervention effects of ADAPT on observed effective parenting behaviors and a mediated intervention effect on child adjustment. Also, Zhang, Lee et al. (2020) found that both fathers and mothers assigned to the intervention condition showed significantly more reductions in nonsupportive emotion socialization behaviors over the course of 2 years compared to the control condition, and that intervention-induced changes in emotion socialization were further associated with decreases in child internalizing and externalizing problems. However, these findings primarily focused on the intervention effects on individual-level behaviors or functioning using global observational ratings and self-reports (parenting behaviors and child mental health outcomes). It is unknown whether the parenting intervention could strengthen dyadic interactions between parent and child.

Effective emotion socialization behaviors call for moment-by-moment coordination and synchrony between parent and child. Parent-child synchrony lays the groundwork for children to learn to regulate their physiology, behaviors, and emotions, and these regulation skills may protect children from developing adjustment problems (Suveg et al., 2019). Behaviorally, synchrony refers to instantaneous and mutual coordination of observed behavioral exchanges between parent and child, such as mutual gazing and shared laughs. Physiologically, synchrony reflects the way in which parent and child physiological states (e.g., heart rate) change together or following one another (Feldman et al., 2011). Positive physiological synchrony is evidenced when parent and child show a similar pattern of increases and decreases relative to their own averages over the course of the task. In contrast, negative physiological synchrony is apparent when parent and child show opposing patterns of increases and decreases relative to their own averages over the course of the task. Study 1 showed the positive association between physiological synchrony and child self-regulation such that positive synchrony is linked to better self-regulation. Physiological synchrony, a measure of dyadic physiological mutuality and concordance, may also be regarded as an intervention outcome.

Intervention Effects on Parent-Child Physiological Synchrony

The effect of family-based interventions on parent and child autonomic nervous activity has been documented in recent studies, primarily with young children. A study tested the longitudinal effect of the Family Nurture Intervention (FNI) in the Neonatal Intensive Care Unit (NICU), a program facilitating mother-infant emotional connection via techniques such as skin-to-skin contact and comfort touch (Welch et al., 2020). Both mothers and children in the intervention condition showed a higher level of parasympathetic activity (i.e., healthier autonomic regulation) compared to those in the control condition 4 to 5 years after the intervention. Another study examined intervention effects of the *Promoting First Relationships* program, a home-visiting program targeting parental sensitivity in maltreating parents and their toddlers, on child parasympathetic regulation (Hastings et al., 2019). Results showed that children of parents who participated in the intervention program showed moderated parasympathetic withdrawal in response to environmental challenges, which indicated a normal and healthy pattern of regulation. In contrast, children of parents in the control condition showed higher levels of RSA withdrawal, which may indicate poorer emotion regulation. In addition, the well-established multi-component intervention, Incredible Years (IY), was found to improve children’s sympathetic and parasympathetic regulation via reductions in negative parenting behaviors (e.g., critical statements, negative commands) in families of children with attention deficit hyperactivity disorder (Bell et al., 2018). Taken together, evidence shows these family-based interventions directly (or indirectly, through changes in parenting behaviors) benefited infants’ and children’s physiological regulation.

However, evidence regarding intervention effects on parent-child real-time behavioral or physiological reciprocity is still sparse. Focusing on infants and toddlers, the *Promoting First Relationships* program was found to increase parental sensitivity, observed during a series of parent-child interactions, such as free play, teaching, and brief separation (Oxford et al., 2016). The Nursing Child Assessment Teaching Scale (NCATS; Barnard, 1994) was used to code parental-child behavioral and affect mutuality, parental verbal and nonverbal support, and sensitive instruction. Another program, focusing on school-aged children, combined Parent Management Training (delivered to parents) and Cognitive-behavioral programs (delivered to children) for families with aggressive children (Granic et al., 2007). The program was found to improve parent-child emotional flexibility during a problem-solving task post-intervention. Specifically, both parents and children's affect were coded using a simplified version of the Specific Affect coding system (SPAFF; Gottman et al. 1996a, b). The affect codes were constructed using state space grid (SSG) analysis to represent the moment-to-moment dyadic changes in parent and child affect (Granic & Lamey, 2002; Hollenstein et al. 2004). Increases in emotional flexibility were indexed via increases in the number of times dyads changed emotional states, increases in the range of emotional states, and decreases in the amount of time when dyads were stuck in a specific emotional state. Although moment-to-moment behavioral dynamics were conceptualized and measured differently in these two studies, they both showed significant intervention effects on parent-child behavioral contingency/coordination.

However, no studies have examined whether patterns in parent–child physiological synchrony may act as a marker of treatment effectiveness in evidence-based family interventions. Since physiological synchrony appears to underlie behavioral reciprocity, and intervention-induced changes in parent-child behavioral coordination may also manifest through physiological synchrony, this exploratory study examines synchrony as a potential marker of intervention effectiveness.

Parental Emotion Socialization and Child Self-Regulation

Children develop emotion regulation capacities primarily through interacting with others, and the attachment relationship with caregivers is a primary source of emotional support (Morris et al., 2017). Parents' emotion socialization behaviors, which includes parents' responses to children's emotions, parents' attempts to directly teach children about emotion regulation and parents' own emotion expressions, have a great impact on the development of emotion management abilities and related outcomes (Eisenberg et al., 1998; Morris et al., 2007, 2017). Children with parents who help them with understanding and regulating emotions tend to manage intense negative emotions more effectively, compared to those with parents who become angry and/or punish their children for negative emotions (Shaffer et al., 2012). This is particularly relevant for children with deployed parents because traumatic deployment-related stressors may disrupt emotion regulation, and hence effective parenting behaviors, especially emotion socialization behaviors.

Parent-child physiological synchrony and parental emotion socialization are interrelated. Parental effective responses to children's emotions require coordination of behavioral and physiological cues between parent and child (Provenzi et al., 2018). Meanwhile, parental sensitivity to the child's subtle signals and emotional needs may further facilitate coordinated behaviors and physiologies (Harrist & Waugh, 2002). Empirical evidence on the interplay between physiological synchrony and emotion socialization is still limited. One study focused on inter-beat interval/IBI synchrony (i.e., the concordance in intervals between parent and child heart beats) and found that synchrony was associated with more psychological availability in a collaborative task and was associated with less psychological control in a conflict task (Han et al., 2019). Another study focused on adrenocortical synchrony and found that synchrony was only present between mothers with higher levels of behavioral sensitivity and their children

(Ruttle et al., 2011). This emerging evidence suggests associations between synchrony and parenting behaviors, especially emotion socialization behaviors.

Parenting interventions may not directly impact physiological synchrony, since the underlying mechanism of this effect and the active component of parenting interventions that improves physiological synchrony is still unknown. Rather, dyads with different valence of synchrony (i.e., positive vs. negative synchrony) and different magnitude of synchrony may show divergent responses to a parenting intervention. Indeed, parental sensitivity has been found to moderate intervention effects on child RSA reactivity such that in the intervention group, greater parental sensitivity was associated with lower levels of child RSA withdrawal (indicative of healthy parasympathetic regulation), whereas parental sensitivity was associated with higher levels of child RSA withdrawal in the control group (Hastings et al., 2019). The results suggested that a parenting intervention may show divergent effectiveness for parents with different baseline levels of sensitivity and responsiveness. In addition, parent-child physiological synchrony may moderate the relation between parenting behaviors and child outcomes. For example, Ahemeitijiang and colleagues (2020) found that IBI synchrony moderated the association between negative emotion-related parenting (i.e., parental psychological control and emotion dysregulation) child aggressive behaviors. Specifically, a positive relationship between negative emotion-related parenting behaviors and child aggression was only observed in dyads with stronger physiological synchrony. It appeared that dyadic synchrony may strengthen the negative impact of ineffective parenting on child behavioral problems. It is also plausible that synchrony may moderate the association between emotion-related parenting/emotion socialization and child self-regulation.

The Current Study

ADAPT is an evidence-based parenting intervention targeting effective parenting behaviors in post-deployed military families. The impact of ADAPT on emotion-related parenting has been well established, such that parents in the intervention condition reported more supportive and less nonsupportive emotion socialization behaviors compared to parents in the control group. Changes in emotion socialization were further found to be associated with fewer child behavior problems (Zhang, Lee et al., 2020). This study sought to explore the role of parent-child physiological synchrony in the ADAPT intervention without making explicit hypotheses due to the fact that this line of research is still in its infancy. First, we aim to explore the intervention effect of ADAPT on parent-child moment-to-moment physiological synchrony at 1-year post-baseline. Second, we aim to explore whether physiological synchrony at baseline would moderate the intervention effect on parental emotion socialization and the link between emotion socialization and child self-regulation. The conceptual model of the second research question is presented in Figure 6.

Method

Participants

This study used a subsample of 108 mother-child dyads at baseline (T1) and 51 mother-child dyads at 1-year follow-up (T3). The 108 dyads were selected at T1 because they had complete RSA data for both mother and child during the baseline/reading task as well as the problem-solving task. The reasons for excluding the 205 dyads in the full sample have been reported in Study 1. Out of the 108 selected dyads at T1, only 51 dyads had complete RSA data for both mother and child during the problem-solving task at T3.

Missingness on RSA data of the rest 57 dyads was due to the following reasons: 1) the family dropped out at T3; 2) the family did not complete T3 in-home assessment; 3) the family completed T3 in-home assessment but inter-beat intervals (IBIs) were not collected; 4) either mother or child refused to wear the IBI recording equipment or did not participate; 5) IBI data not recorded because of administrative error or equipment malfunctions; 6) the start time of IBI data recording or the problem-solving task was unavailable because of issues with video-recording; 7) raw IBI data of either mother or child contained excessive artifacts; 8) RSA data of either mother or child contained less than 5 segments. Of the 51 mother-child dyads at T3, mothers reported a mean age of 35.65 years (*SD* = 5.37, range = 26 - 47), and 4 mothers (7.8%) were deployed. The majority were identified as Caucasian/White (92.2%). About half of the mothers completed a 4-year college degree or above (53.1%), and 38.8% attended some college or received an Associate's degree. 43.8% of the mothers reported annual household income between $40,000 and $80,000 and 27.2% reported annual household income between $80,000 and 120,000. The target children were on average 9.84 years (*SD* = 2.50, range = 5 - 15), with 29 boys (56.9%) and 22 girls (43.1%).

Procedure

Participants were recruited through presentations at mandatory pre-deployment and reintegration events for all NG/R personnel, mailings from the Minneapolis Veterans Affairs Medical Center to all OIF/OEF veterans, flyers throughout the Minneapolis/St. Paul area, social media, and word of mouth. Interested families were directed to a brief online screener, where they completed the informed consent. Part of the initial online assessment was completed online, which included self-report measures. After completion of the initial survey, research staff set up an in-home assessment, during which additional measures (questionnaire and observational) were collected with the parent(s) and the target child. All study procedures were approved by the University of Minnesota's Institutional Review Board.

Following the baseline assessment, 40% of families were randomized to a services-as-usual condition (online parenting resources), while 60% of families were randomized to the intervention condition. We oversampled for the intervention condition on a 3:2 ratio, ensuring sufficient power to detect intervention effects. In the current sample, 31 families (60.8%) were in the intervention group and 20 families (39.2%) were in the control group. Subsequent assessments were conducted at 1-year follow-up (approximately 6-months post-intervention) and 2-year follow-up, which included both an online survey and in-home assessment.

Intervention

The ADAPT intervention now is available in multiple formats, but for the original study, it was a 14-week group-based program developed for post-deployed military families. Each group session was facilitated by 2-3 trained facilitators (i.e. military and non-military professional service providers) lasting for two hours per week, and there were 6-15 parents per group. The program targeted six components of positive parenting: skill encouragement, positive involvement, problem-solving, monitoring, discipline, and emotion socialization (Gewirtz et al. 2018b). Mindfulness practices (e.g., body scan, mindful eating) were infused into each session to foster parents' present moment non-judgmental awareness and acceptance of their emotions and cognitions. Emotion coaching skills, such as being aware of children's emotions, labeling and validating emotions, and helping children resolve emotional challenges, were also taught and practiced in each session. Materials were delivered using active teaching techniques, such as role-play, observation, and discussion in small groups. Group sessions were videotaped to measure implementation fidelity. Online resources including videos demonstrating parenting skills and mindfulness practices were also available to the parents.

Measures

Intervention Condition. Group assignment was coded as 1 = *intervention*, 0 = *control*. The intent-to-treat (ITT) was employed to analyze intervention effects such that all families that were randomized were included in the analyses regardless of their completion of the intervention.

Parental Emotion Socialization. Mothers' emotion socialization was measured using the Coping with Children's Negative Emotions Scale (CCNES; Fabes et al., 1990) at baseline and 1-year follow-up. This scale has been shown to have adequate validity and reliability (Fabes et al., 2002). Twelve hypothetical scenarios in which children may experience negative emotions were shown to parents. However, because of a technical problem[1], one scenario was not successfully delivered to some participants at baseline. The scenario was excluded from our analysis at baseline and 1-year follow-up to make the data consistent and comparable. Parents indicated how likely they would respond in each of six ways to their children's negative emotions on a 7-point Likert scale (1 = *very unlikely*, 7 = *very likely*). The six subscales were: emotion-focused reaction (EF, e.g. "comfort my

[1] Scenario 6 was removed. The scenario is "If my child is participating in some group activity with his/her friends and proceeds to make a mistake and then looks embarrassed and on the verge of tears."

child and try to get him/her to forget about the accident"); problem-focused reaction (PF, e.g. "talk to my child about ways to make it hurt less, such as relaxing so it won't hurt or taking deep breaths"); expressive encouragement (EE, e.g. "encourage my child to talk about his/her nervous feelings); minimization reaction (MR, e.g. "tell my child that he/she is over-reacting"); punitive reaction (PR, e.g. "tell him/her to shape up or he/she won't be allowed to do something he/she likes to do"); and distress reaction (DR, e.g. "remain calm and not let myself get anxious", reverse-coded). According to Fabes et al. (2002), EF, PF, and EE subscales were grouped into supportive emotion socialization, and MR, PR, and DR subscales were groups into nonsupportive emotion socialization. Mean scores of the three subscales were created to indicate supportive and nonsupportive emotion socialization respectively at baseline and 1-year follow-up.

Child Self-Regulation. Child self-regulation was measured with the parent version of the Behavioral Assessment Scale for Children-Second Edition (BASC-2-PRS and BASC-2-TRS; Reynolds & Kamphaus, 2004) at baseline and 2-year follow-up reported by both parents. Due to the relatively large amount of missing data on the teacher-reported scales at 2-year follow-up, teachers' reports were not included in the following analyses. The Anger Control, Emotional Self-Control, and Executive Functioning subscales were included in the BASC-2 PRS as content scales. Parents were asked to rate the frequency of children's behaviors on a Likert scale from 0 (*never*) to 3 (*almost always*). The Anger Control scale reflects "the tendency to become irritated and angry quickly and impulsively, coupled with an inability to regulate affect and control during such periods". This scale includes 9 items (e.g., "Hits other children", "Threatens to hurt others", "Argues when denied own way"). The Emotional Self-Control scale reflects "the ability to regulate one's affect and emotions in response to environmental changes". This scale includes 6 items (e.g., "Loses temper too easily", "Has poor self-control", "Is easily upset"). The Executive Functioning scale reflects "the ability to control behavior by planning, anticipating, inhibiting, maintaining goal-directed activity, and reacting appropriately to environmental feedback in a purposeful, meaningful way". This scale includes 10 items (e.g., "Is easily distracted", "Acts without thinking", "Is a 'self-starter'"). T-scores were computed and used in the current analysis. These scales were only available for children above age 6, therefore, data for children below age 6 (n = 21 at baseline and n = 0 at 2-year follow-up) were missing. Mean scores of father reports and mother reports were computed at baseline and 2-year follow-up respectively, and the mean scores were used in the final analyses.

Parent and Child RSA. Consistent with Study 1, IBI data at T3 were recorded during in-home assessments, administered by 2-3 trained technicians. A Polar RS800CX (Polar Electro, US) heart rate monitor was used to assess IBIs at a sampling rate of 1000 Hz. IBI data of mother and child during the problem-solving task were used, and the raw IBI data were cleaned following exactly the same protocol as Study 1. RSA was quantified using the Porges–Bohrer method (Porges & Bohre, 1990) using CardioBatch Plus (Brain-Body Center for Psychophysiology and Bioengineering, University of North Carolina, Chapel Hill, 2016), and the mean RSA magnitude was estimated for each 30-s epochs for mother and child separately. On average, dyads had 9.41 epochs during the 5-minute task.

Covariates. Parental post-traumatic stress disorder (PTSD) symptoms were measured using the Post-Traumatic Stress Checklist, a self-report measure consisting of 17 items that assess PTSD symptoms in response to stressful military experiences. The PCL-

Military version was administered to the deployed mothers (PCL-M; Weathers et al., 1994) while the civilian version was administered to the non-deployed mothers (PCL-C). Other parent-related covariates include parent education, parent age, years of marriage, and household income. Years of marriage was the average of husband and wife reports of years married to the current spouse.

Data Analytical Strategy

To test the first research question regarding the intervention effect on mother-child physiological synchrony at 1-year follow-up (T3), preliminary analyses were first conducted in R version 4.0.3 (R Core Team, 2020) to examine descriptive statistics, the overall trend of RSA trajectories across the problem-solving task, and the dyadic RSA trajectories for each dyad. The lmer package in R (Bates et al., 2015) was used to run random intercept and random slope multilevel models for mother and child separately to estimate the overall trend across time. RSA trajectories during the problem-solving task across all epochs for mother and child are shown in Figure 7 and the mean RSA magnitude for each epoch is reported in Table 7.

The primary analyses examined the ITT effect on T3 synchrony controlling for synchrony at T1 and other covariates, such as child age, child gender, maternal age, maternal PTSD symptoms, maternal education level, and household income. Because more than half of dyads (53.7%) who had complete synchrony data at baseline had missing data on T3 synchrony, a listwise deletion approach was used so that only those dyads with complete T3 RSA data were included in the primary analyses. Dyadic synchrony was still estimated using a multilevel growth curve modeling approach. However, to reduce the complexity of conducting two multi-level models examining the association between T1 synchrony and T3 synchrony, as well as the intervention effect, the factor scores of the random slope indicating concurrent synchrony and lagged synchrony for each dyad were saved out as between-level variables at T1 and T3 respectively. It should be noted that this method did not account for the measurement error in estimating the random slopes and may lead to biased results. The ITT effect was estimated using linear regression analyses in M*plus* 8.3 (Muthén & Muthén, 1998-2017).

To test the second research question regarding whether synchrony at T1 moderates the ITT effects on parental emotion socialization and the association between emotion socialization and child self-regulation, the main ITT effect on emotion socialization at T3 was first tested, as well as whether emotion socialization at T3 mediated the ITT effect on child self-regulation at T4 in M*plus* 8.3 (Muthén & Muthén, 1998-2017). The indirect effect was estimated using bias-corrected bootstrapping with 2000 iterations (Fritz & MacKinnon, 2007). The 95% confidence intervals were also estimated. Then, the moderation effect of synchrony was tested by adding the interaction term of synchrony and ITT in the model predicting changes in emotion socialization and adding the interaction term of synchrony and emotion socialization at T3 in the model predicting changes in child self-regulation. The factor scores estimating the magnitude of concurrent synchrony and lagged synchrony for each dyad at T1 were used in the moderation analyses (rather than estimating the moderation effect of synchrony in multilevel models) to eliminate model misspecification by estimating moderated mediation effects in multilevel models. Model fit was evaluated using the recommended criteria by Hu and Bentler (1999); a model was considered acceptable with a comparative fit index (CFI) greater than .95, a standardized root mean-square residual (SRMR) below .08, and a root mean square error of approximation (RMSEA) below .06.

Results

Preliminary Analyses

Tests of the overall trend of mother and child RSA at 1-year follow-up showed that a linear decrease (RSA withdrawal) was observed in child data, b = -.02, t(49) = -2.06, p = .045, but the same trend was not found in mother RSA, b = -.01, t(45) = -0.75, p = .457. Nevertheless, both mothers' and children's RSA were detrended in the following analyses to prevent confounding effects of trend synchrony (Helm et al., 2018). RSA trajectories during the problem-solving task across all epochs for mother and child were shown in Figure 7. In addition, the mean RSA magnitude for each epoch was reported in Table 7.

To test the first research question, synchrony coefficients at baseline were calculated for the 51 dyads who had completed RSA data at 1-year follow-up. Bivariate correlations between synchrony coefficients at baseline and synchrony coefficients at 1-year follow-up were presented in Table 8. Positive longitudinal associations between baseline and 1-year were found in coefficients indicating lagged synchrony in the child model (r = .29) and concurrent synchrony in the mother model (r = .40). Surprisingly, negative longitudinal associations between baseline and 1-year were found in coefficients indicating concurrent synchrony in the child model (r = -.41) and lagged synchrony in the mother model (r = -.29). The results hold when partial correlations were estimated after controlling for child age. Nevertheless, child age was positively associated with both concurrent (r = .37) and lagged (r = .29) synchrony in the child model within the 51 dyads (see Table 9).

The mean differences between synchrony coefficients at baseline and 1-year follow-up were calculated using repeated-measure t-tests. Results showed significant increases from baseline to 1-year follow-up in concurrent ($t(50) = -4.72$, $p = .000$) and lagged synchrony ($t(50) = -3.50$, $p = .001$) in the child model and concurrent synchrony ($t(50) = -3.44$, $p = .001$) in the mother model. Lagged synchrony in the mother model also showed a trend-level increase without reaching statistical significance ($t(50) = -1.35$, $p = .185$).

To test the second research question, synchrony coefficients were calculated for the 108 dyads who had complete RSA data at baseline. Bivariate correlations among synchrony coefficients, parental emotion socialization, and child self-regulation showed that synchrony coefficients in child model at baseline were negatively associated with most self-regulation measures at baseline (rs = -.27 ~ -.22), such that higher synchrony was associated with better self-regulation. The same patterns of correlation were not found between synchrony coefficients in the mother model at baseline and self-regulation measures. In addition, concurrent synchrony in the child model was associated with better emotional control at 2-year follow-up (r = .21). Lagged synchrony in the child model was associated with better executive functioning at 2-year follow-up (r = .21). Nonsupportive emotion socialization at baseline was significantly associated with worse self-regulation at baseline (rs = .26 ~ .33). However, no significant associations were found between supportive emotion socialization and child self-regulation at baseline, or between emotion socialization at 1-year follow-up and child self-regulation at 2-year follow-up.

Child age was negatively associated with lagged synchrony in the child model (r = -.22) and concurrent synchrony in the mother model (r = -.24).

Primary Analyses

The first research question was examined by estimating the ITT effect on dyadic synchrony at 1-year follow-up controlling for the corresponding synchrony coefficient at baseline as well as the identified covariates. Four models were conducted to estimate the ITT effect on concurrent and lagged synchrony in the child model, and concurrent and lagged synchrony in the mother model. As shown in Table 11, none of the estimated ITT effects were statistically significant.

The second research question was examined by estimating the mediation effect of parental emotion socialization and the moderation effect of dyadic synchrony on the ITT effect on child self-regulation (see Figure 6 for the conceptual model). The indirect effects were first estimated for the three self-regulation measures separately with the standardized coefficients presented in Table 12. The indirect effect was only found to be marginally significant in predicting child lack of anger control at 2-year follow-up mediated through decreases in mothers' non-supportive emotion socialization (β = -.03, p = .079). Thus, the moderation effect of physiological synchrony was only estimated for this mediational pathway. Specifically, the moderation effects were tested on both the a path (ITT → non-supportive emotion socialization at 1-year) and the b path (non-supportive emotion socialization at 1-year → child lack of anger control at 2-year). Results showed that the concurrent synchrony in the child model significantly moderated both the a path (β = .45, p = .001) and the b path (β = -.23, p = .016). Moderation effects of other synchrony coefficients were not significant and are presented in Table 13. The indirect intervention effects on child lack of anger control through non-supportive emotion socialization were estimated at the low (*M-SD*; synchrony coefficient = -.13), medium (*M*; synchrony coefficient = -.06), and high (*M+SD*; synchrony coefficient = .01) levels of the moderator, and the results showed that the indirect effects were statistically significant at low (B = -4.25, SE = 1.41, p = .003) and medium (B = -1.30, SE = .51, p = .011), but not high (B = .04, SE = .22, p = .847) levels of concurrent synchrony. In other words, for dyads with negative concurrent physiological synchrony, the ADAPT program showed a significant indirect effect on child anger control through reductions in mother's non-supportive emotion socialization behaviors.

Discussion

To our knowledge, this study is the first to investigate the effect of a parenting intervention on parent-child physiological synchrony. The overarching goal of this study was to explore the role of physiological synchrony, either as a proximal outcome or as an intervention moderator, in a parenting intervention. We found that, although the parenting intervention did not directly affect physiological synchrony, physiological synchrony at baseline moderated the indirect effect of the intervention on child self-regulation through parental emotion socialization. Specifically, the indirect intervention effect was only found to be significant for dyads who showed negative mother-to-child concurrent synchrony (prediction of child RSA from mother concurrent RSA) at baseline. The moderation effects of other synchrony coefficients were not found.

Longitudinal Association in Dyadic Physiological Synchrony

Within the 51 dyads with complete RSA data at both baseline and 1-year follow-up, we observed an expected pattern of positive longitudinal association in lagged synchrony in child model and concurrent synchrony in mother model and an unexpected pattern of negative longitudinal association in concurrent synchrony in child model and lagged synchrony in mother model. The contradictory results could not be explained by the longitudinal association in RSA values across baseline and 1-year, since both child and mother's mean RSA values during the reading task and problem-solving task were positively and significantly correlated across time (see table 10). These results may be better understood in conjunction with the mean-level changes in synchrony across time. In fact, we also observed significant increases in three out of four synchrony coefficients from baseline to 1-year follow-up across intervention and control conditions. It is noteworthy that mother-child dyads went through the same dyadic problem-solving task during the assessment at 1-year follow-up as they did during the baseline assessment, although the "hot topic" the mother selected might have differed. RSA data were cleaned and analyzed using the same protocol. It was surprising that synchrony in the child model was negatively associated with age in the 108 dyads included in study 1, whereas the association was positive among the 51 dyads included in study 2. It would be reasonable to observe within-dyad increases in synchrony with age if a between-dyad positive correlation between synchrony and child age was observed. However, given the conflicting results and the lack of prior evidence, it is still premature to speculate that child age/development contributed to the mean-level changes in synchrony.

Another potential explanation is the enhanced familiarity and attenuated stress reactivity during the second assessment. Since RSA synchrony has been found to be sensitive to environmental variation (Lunkenheimer et al., 2017), such as the emotional valence and the features of the interaction tasks, it may be that dyads are more likely to show positive synchrony when the social contextual demands are reduced. Future work is needed to replicate the current findings in a large sample during other interaction tasks and examine how task characteristics influence physiological synchrony. Additionally, the effect of average RSA across epochs during the reading task and problem-solving task on RSA synchrony was not taken into account. Rather, we parsed out the between-person differences in average RSA by using the group-mean centered RSA in the multi-level models estimating RSA synchrony. The average RSA during the reading task may reflect individual's capacity to maintain physiological homeostasis, and the average RSA during the problem-solving task may reflect physiological reactivity in response to environmental demands. A recent study found the interaction effect of child externalizing problems and average RSA during task on RSA synchrony (Lunkenheimer et al., 2021). Future studies may further investigate the interplay between RSA synchrony and average RSA during challenging tasks.

Intervention Effects on Physiological Synchrony

The null findings of intervention effect on physiological synchrony suggested that parent-child physiological synchrony was not directly affected by the ADAPT parenting intervention. Although prior evidence has shown a parenting intervention to influence child parasympathetic regulation (Hastings et al., 2019; Katz et al., 2020), no studies have empirically tested whether and how a parenting intervention may influence parent-child physiological synchrony. In addition, the optimal timescale on which to observe intervention-induced changes in synchrony is unknown. We did not observe changes in physiological synchrony at 1-year post-baseline (i.e., 6-month post-intervention), but it is possible that changes in physiological synchrony may take longer to be detected and the time interval for changes may vary by each family. Also, it is still unknown whether physiological synchrony could serve as an indicator or biomarker of the impact of a parenting intervention and whether changes in this indicator would further translate to changes in distal outcomes, such as parenting and child socio-emotional outcomes. The answers to these questions may differ across different targets and key components of parenting interventions. Parenting interventions that directly target parental sensitivity and responsiveness to children's emotional cues may show larger benefits to parent-child behavioral and physiological synchrony (Calkins, 2011; Hastings et al., 2019).

Another avenue to address dyadic physiological synchrony might be via improving parents' and children's emotion regulation. A body of research has shown the detrimental impact of parental emotion dysregulation and mental health problems, as well as child behavioral problems, on dyadic synchrony (Lunkenheimer et al., 2015, 2018; Woody et al., 2016). Parents who are more capable of managing their emotions may show higher levels of attunement and contingency to children's emotional signals (O'Brien et al., 2020). It is possible that the ADAPT intervention's broader focus on parenting behaviors, such as problems solving and discipline, rather than a sole or major focus on emotion regulation and sensitivity might be a reason that no intervention effect on dyadic physiological synchrony was found. Future studies should elucidate the mechanism and key components of parenting interventions that benefit parent-child physiological synchrony.

Moderation Effects of Physiological Synchrony

The second aim of the current study was to examine the moderating role of physiological synchrony on the intervention's effect on emotion socialization and child self-regulation. First, we found that parental non-supportive emotion socialization, but not supportive emotion socialization, served as the mechanism explaining the intervention effect of ADAPT on child self-regulation. The results are consistent with a prior ADAPT study, which also found significant intervention effects on reducing parents' non-supportive emotion socialization but not increasing supportive emotion socialization across 2 years (Zhang, Lee et al., 2020). That study also found a significant association between changes in non-supportive emotion socialization and child internalizing and externalizing behavior across 2 years. In fact, reducing punitive and avoidant behaviors in response to children's emotional expressions and fostering emotion recognition and acceptance are key elements of the ADAPT program, and these elements have been proposed as influencing child self-regulation and socioemotional adjustment over the long term (Eisenberg et al., 1998).

Second, we found the moderation effect of mother-to-child concurrent synchrony on the indirect effect of the ADAPT intervention on child anger control through changes in non-supportive emotion socialization, such that the indirect intervention effect was only found in dyads with negative synchrony at baseline. The moderation effect of dyadic physiological synchrony on the association between parenting and child outcomes is still understudied and, to our knowledge, only one empirical study investigated this effect in school-aged children (Ahemaitijiang et al., 2020). The study found a positive cross-sectional association between negative emotion-related parenting behavior and child aggression in dyads with relatively higher levels of IBI synchrony (i.e., positive synchrony). However, the current study found a significant positive longitudinal association between mothers' non-supportive emotion socialization and child lack of anger control in dyads with negative RSA synchrony. It is unknown whether physiological synchrony is indicative of child sensitivity/vulnerability to environmental characteristics, and whether children who showed higher levels of physiological synchrony are at greater/lesser risk of behavioral problems. More studies are needed to test the effect of physiological synchrony on child adjustment outcomes across contexts and family risk status and uncover the risk/protective role of physiological synchrony.

In spite of the inconsistency with prior literature, it is noteworthy that concurrent physiological synchrony, which was correlated with better self-regulation in this study, moderated the indirect intervention effect of ADAPT. Similarly, prior research (Zhang et al., 2018) found that the ADAPT program showed a significant impact on mothers' emotion socialization behaviors among those with greater risk of experiential avoidance (a correlate of emotion dysregulation). In this study, dyads with negative physiological synchrony showed more gains in parental emotion socialization and child self-regulation. Children in these dyads presumably had poorer self-regulation at baseline but showed greater gains at 2-year follow-up. Since ADAPT integrated mindfulness and emotion coaching components to foster parents' emotion awareness and regulation and enhance effective responses to children's emotions, we speculated that those parents with lower emotional sensitivity and responsiveness might benefit more from the intervention, and their improvement in emotion socialization would further lead to increases in children's self-regulation. These findings are in line with compensatory effects in the risk moderation hypothesis, which suggests that prevention or intervention programs are more effective for high-risk subgroups (Shelleby & Shaw, 2014).

Limitations and Future Directions

One of the biggest limitations of this study is the small sample size at 1-year follow-up, which limited in-depth examination of the longitudinal changes in physiological synchrony as well as the intervention effects. The interpretation of the mean-level increases and the contradictory longitudinal correlations in physiological synchrony across time is impeded due to the limited power and lack of prior evidence on the long-term changes in physiological synchrony over months and years. A longitudinal design should be incorporated into the investigation of parent-child physiological synchrony in future research. Also, more research is needed to investigate the factors that contribute to the longitudinal negative/positive associations and increases in dyadic synchrony across time.

With respect to the moderated mediation effect of the ADAPT intervention, we only found significant effects on child anger control reported by parents. Teacher-report data were not used because of unneglectable amount of missing data. A more comprehensive measurement of child self-regulation, incorporating parents', teachers', and self-reports, is needed to better understand the impact of a parenting intervention on child self-regulation.

This study examined the role of physiological synchrony in the context of a parenting intervention that included targeting both effective emotional and behavioral parenting. Behavioral components such as discipline and problem solving may not directly improve physiological synchrony, compared to components that target emotional availability and sensitivity. The intervention effect, as well as underlying mechanism and active components, should be investigated in intervention programs with a sole focus on parental emotion socialization and responsiveness.

Implications

This study found that mother-child physiological synchrony increased over 1 year, although there were no significant differences between the intervention and control conditions. Physiological synchrony at baseline moderated the mediation effect of the ADAPT intervention on child self-regulation through emotion socialization, such that the ADAPT intervention improved child self-regulation through reductions in mothers' non-supportive emotion socialization among those who showed lower and medium levels of physiological synchrony. This study speaks to the importance of focusing on dyadic-level processes as a potential indicator of treatment effect, especially in interventions aiming to facilitate interpersonal relationships. In addition, this study is the first to test the moderating role of dyadic synchrony, which extends our understanding of the question "for whom does the intervention work" (Yirmiya, 2010). Future studies are needed to replicate these findings in other intervention programs, such as programs targeting parental sensitivity and attachment relationships and biofeedback interventions that target parents' and children's phycological regulation (Wheat & Larkin, 2010).

General Discussion

Parent-child physiological synchrony, which is characterized by the matching or concordance of physiological states among parents and children, has been posited to be linked to children's self-regulation and adaptive outcomes in prior research (Feldman et al., 2011; Suveg et al., 2016). However, the association between physiological synchrony and child regulatory outcomes was rarely supported in empirical studies, especially in the at-risk population. Also, no research has investigated the impact of parenting interventions on dyadic synchrony. This dissertation aims to contribute to the literature on physiological synchrony by examining the developmental function of synchrony, the longitudinal changes in synchrony, as well as the role that synchrony plays in a parenting intervention.

Specifically, Study 1 addressed the research gaps in the extant literature by examining the relationship between mother-child physiological synchrony and child self-regulation in post-deployed military families. Additionally, the associations of synchrony with child age, parental emotion regulation, and parenting behaviors were also tested. Using a multilevel growth modeling approach to model dynamic changes in RSA during a problem-solving task, results suggested the adaptive function of synchrony in that children's parasympathetic synchrony with parents is linked to better self-regulation. Child age played a role in lagged synchrony, such that younger children tended to show positive lagged synchrony with mothers while older children tended to show negative lagged synchrony. Contradictory findings were observed when examining the relationship between parental emotion regulation, parenting behaviors, and synchrony. Mothers' emotion dysregulation was found to be associated with higher levels of lagged synchrony. Also, synchrony was found to be linked to both positive (i.e., fewer displays of anger/disgust, more positive physical behaviors, and less negative directive behaviors) and negative parenting behaviors (i.e., fewer displays of positive affect).

Building on the results of Study 1, Study 2 explored the effect of the ADAPT parenting intervention on dyadic synchrony, as well we the moderation effect of synchrony at baseline on the indirect intervention effect on child self-regulation through changes in parental emotion socialization. Although the hypothesized intervention effect was not observed, dyads with negative synchrony at baseline were found to benefit more from the ADAPT intervention. The changes in emotion socialization behaviors were further associated with better child self-regulation.

Findings in both studies highlighted the importance of parent-child physiological synchrony in self-regulation development in children in military families who are at risk for developing maladaptive behaviors. It is noteworthy that this dissertation is the first attempt to examine longitudinal continuity/changes in parent-child physiological synchrony, also it is the first to explore the impact of a parenting intervention on physiological synchrony.

In spite of the significant contributions to the current literature, this dissertation also raises several questions and directions for future research to better understand physiological synchrony as well as its functions and developmental significance. First, future studies must investigate the time scale in quantifying RSA and modeling RSA synchrony, as well as the appropriate time-lag to model lagged synchrony. Also, future work should uncover the changes in dyadic synchrony in longer timescales (e.g., across days, months, and years). In addition, the role of child development on synchrony is still under investigation. As children gain more autonomy, the balance between self-regulation and co-regulation might become more salient. These two processes may be intertwined to facilitate emotional and behavioral regulation. Future studies may take into account the spontaneous stress response and self-initiated regulatory behaviors while examining interpersonal synchrony. Second, physiological measures of synchrony should be examined in conjunction with real-time behavioral observations of children's instantaneous stress-related reactivities and parents' behaviors during interactions. The moment-to-moment assessment of dyadic behaviors as well as physiological reactivities may greatly contribute to our understanding of the interplay between synchrony, parenting, parental emotion regulation, and child functioning. Third, although only parasympathetic synchrony is the main focus of this dissertation, synchrony in other biological systems (i.e., sympathetic synchrony, adrenocortical synchrony, and central nervous system synchrony) has been widely reported. Future work should expand on studies synchrony across biological systems to examine whether there is cross-system coordination. Lastly, synchrony may not be a static characteristic of a dyad, rather it may be a dynamic process and is constantly changing in response to changes in internal stress reactivity and external environmental challenges (Mayo & Gordon, 2020; Ravindran et al., 2021). More work should be devoted to investigating the dynamic changes in dyadic synchrony and interpersonal and intrapersonal factors that contribute to this dynamic change.

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Appendices

Table 1. Sample demographics and the demographic differences between the subsample used in the current study and the remainders in the full sample

	The current subsample (n = 108)		Reminders in the full sample (n = 205 for mother and n = 228 for child)		*t* or chi-square
	N (percent)	*M* (*SD*)	N (percent)	*M* (*SD*)	
Mom Age		35.79 (5.65)		35.63 (6.03)	$t(305) = -.22$
Mom years of marriage		10.17 (5.93)		9.09 (5.02)	$t(273) = -1.58$
Education					
4-year college degree or higher	54 (50.0 %)		107 (53.2%)		$X^2(1, N = 309) = .29$
Some college and high school	54 (50.0%)		94 (46.8%)		
Annual household income					
Below $40,000	20 (18.5%)		40 (20.2%)		
$40,000 - $79,999	51 (47.2%)		79 (39.9%)		$X^2(3, N = 306) = 4.91$
$80,000 to $119,999	31 (28.7%)		53 (26.8%)		
More than $120,000	6 (5.6%)		26 (13.1%)		
Deployment status					
Deployed	17 (15.7%)		39 (19.0%)		$X^2(1, N = 313) = .52$
Non-deployed	91 (84.3%)		166 (80.1%)		
Child age		8.85 (2.64)		8.16 (2.44)	$t(334) = -2.35$*
Child gender					
Boy	60 (55.6 %)		96 (42.1%)		$X^2(1, N = 336) = 5.33$*
Girl	48 (44.4%)		132 (57.9%)		

Note. *$p < .05$. **$p < .01$. ***$p < .001$.

Table 2. Descriptive statistics and bivariate correlations among Study 1 key variables

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1.BL RSA C	—																				
2.BL_RSA_M	.07	—																			
3.PS_C_Mean	.80**	.12	—																		
4.PS_M_Mean	.04	.88**	.11	—																	
5.Mom Emotion Regulation Difficulties	-.04	-.24*	-.15	-.27**	—																
6.RACS_ directive	.12	-.19	.00	-.21	.11	—															
7.RACS_ neg directive	.13	-.02	.14	-.06	.02	.23	—														
8.RACS_ pos physical	-.05	.06	-.02	.15	.06	.29*	.00	—													
9.RACS_ neg physical	-.06	.08	.03	-.05	.07	.47**	.01	.35**	—												
10.RACS_ anger/disgust	-.02	-.19	-.03	-.08	.07	.13	.32**	-.13	.01	—											
11.RACS_ pos affect	.16	-.06	.13	-.03	-.02	-.08	.05	-.04	-.05	.27*	—										
12.PRS_Lack of AC	-.19	-.04	-.22*	-.02	.16	-.05	-.04	.09	-.13	-.06	-.31*	—									
13.PRS_Lack of EC	-.20	-.14	-.24*	-.12	.29**	-.09	.08	.00	-.07	.04	-.07	.79**	—								
14.PRS_Lack of EF	-.23*	-.08	-.27*	-.09	.23*	-.02	-.05	.20	-.07	-.05	-.22	.86**	.83**	—							
15.TRS_Lack of AC	-.15	-.23	-.08	-.13	-.03	.11	-.05	.27	-.14	-.19	-.13	.53**	.34**	.47**	—						
16.TRS_Lack of EC	-.22	-.25*	-.11	-.16	-.11	-.01	.00	.10	-.14	-.26	-.26	.53**	.37**	.44**	.83**	—					
17.TRS_Lack of EF	-.06	-.25*	-.03	-.16	-.02	.11	-.03	.03	-.17	-.21	-.28	.52**	.47**	.46**	.80**	.83**	—				
18.Mom PTSD	.11	.04	.04	.03	.48**	-.04	.13	-.04	-.10	-.01	-.17	.23*	.29**	.33**	-.09	-.08	.01	—			
19.Mom Age	.24*	-.34**	.13	-.35**	.04	-.03	-.27*	-.13	-.14	-.04	-.01	-.02	.02	-.05	.05	.04	.09	.061	—		
20.Mom Rears of Marriage	.13	-.26*	.08	-.26*	.05	-.03	-.25*	-.11	-.08	.16	.02	-.10	-.05	-.11	-.16	-.10	-.06	.163	.78**	—	
21.Child Age	.19	-.10	.18	-.16	-.11	-.20	-.08	-.40**	-.23*	.18	.24*	-.17	-.11	-.09	-.13	-.18	-.20	-.02	.41**	.38**	—
M	6.98	6.27	6.84	6.27	66.73	.65	.02	.23	.03	.51	1.25	53.40	52.91	53.66	49.49	50.07	50.84	26.45	35.79	10.17	8.85
SD	1.05	1.09	.93	1.06	18.54	.68	.05	.41	.12	.85	1.28	8.57	10.13	8.89	8.00	9.36	9.72	9.00	5.65	5.93	2.64

Note. BL_RSA = Mean RSA during reading baseline task; PS_RSA = Mean RSA during problem-solving task; DERS = Difficulties in Emotion Regulation; RACS = parenting behaviors coded using the Relationship Affect Coding System; AC = Child Anger Control; EC = Child Emotion Control; EF = Child Executive Functioning; PRS = Parent Rating Scale; TRS = Teacher rating Scale.
*$p < .05$. **$p < .01$. ***$p < .001$.

Table 3. Descriptive statistics for mother and child RSA by epoch during the problem-solving task at baseline

	Epoch	N	Min	Max	*M*	*SD*
Child RSA	1	108	3.63	9.48	6.89	1.19
	2	108	2.59	9.57	6.90	1.16
	3	108	2.97	9.09	6.79	1.08
	4	108	3.51	9.17	6.83	1.05
	5	107	4.47	9.14	6.96	1.01
	6	105	4.43	9.35	6.91	1.00
	7	104	4.00	9.53	6.87	1.10
	8	100	3.75	9.11	6.83	1.11
	9	96	3.25	9.22	6.81	1.13
	10	80	3.99	9.13	6.83	1.10
	11	10	5.71	8.85	7.02	1.04
Mother RSA	1	108	3.03	9.57	6.21	1.16
	2	108	3.36	9.53	6.35	1.19
	3	108	2.06	9.80	6.41	1.21
	4	108	3.00	9.12	6.29	1.16
	5	107	2.59	9.26	6.30	1.23
	6	105	3.19	9.24	6.35	1.17
	7	104	1.99	9.56	6.19	1.16
	8	100	2.58	9.44	6.19	1.19
	9	96	2.80	9.23	6.21	1.09
	10	80	2.71	8.98	6.29	1.30
	11	10	4.39	7.84	6.44	0.97

Table 4. Null Multilevel Growth Curve Model Estimates: Concurrent and Lagged Synchrony in the Mother Model and the Child Model

	Mother Model (Child-to-Mother Effects)					Child Model (Mother-to-Child Effects)			
	Concurrent Model		Lagged Model			Concurrent Model		Lagged Model	
	Estimate (SE)	*p*	Estimate (SE)	*p*		Estimate (SE)	*p*	Estimate (SE)	*p*
Fixed Effects					Fixed Effects				
Intercept	**6.338 (.106)**	.000	**6.400 (.112)**	.000	Intercept	**6.909 (.116)**	.000	**6.909 (.103)**	.000
Time	**-.016 (.007)**	.024	**-.027 (.008)**	.001	Time	-.016 (.010)	.106	-.015 (.009)	.109
Child Concurrent RSA	-.044 (.029)	.123			Mother Concurrent RSA	-.061 (.036)	.084		
Mother Lagged RSA			.000 (.034)	.995	Child Lagged RSA			.070 (.043)	.104
Child Lagged RSA			-.009 (.039)	.806	Mother Lagged RSA			-.065 (.044)	.139
Random Effects					Random Effects				
Between Dyad Intercept	**1.086 (.167)**	.000	**1.110 (.167)**	.000	Between Dyad Intercept	**.823 (.116)**	.000	**.810 (.115)**	.000
Within Dyad Residual	**.295 (.019)**	.000	**.264 (.019)**	.000	Within Dyad Residual	**.348 (.026)**	.000	**.306 (.023)**	.000
Child Concurrent RSA	.004 (.011)	.746			Mother Concurrent RSA	.010 (.019)	.580		
Mother Lagged RSA			.012 (.016)	.438	Child Lagged RSA			**.045 (.013)**	.000
Child Lagged RSA			.034 (.022)	.119	Mother Lagged RSA			.037 (.026)	.153
-2LL	2063.0		1821.6		*-2LL*	2187.0		1927.5	
AIC	2077.0		1841.6		*AIC*	2201.0		1947.5	

Note. Unstandardized estimates and standard errors in parenthesis. Significant results are in bold. AIC = Akaike Information Criterion; -2LL = -2 Log Likelihood, relative model fit statistics.

Table 5. Covariation Estimates for the Association Between Synchrony Coefficients and Self-Regulation

	Mother Model (Child-to-Mother Effects)				Child Model (Mother-to-Child Effects)			
	Concurrent Synchrony		Lagged Synchrony		Concurrent Synchrony		Lagged Synchrony	
Self-Regulation Measures	Estimate (SE)	*p*	Estimate (SE)	*p*	Estimate (SE)	*p*	Estimate (SE)	*p*
PRS Lack of Anger Control	-.100 (.365)	.784	.322 (.343)	.348	-.255 (.517)	.622	**-1.199 (.613)**	.051
PRS Lack of Emotion Control	-.139 (.414)	.737	.278 (.430)	.519	-.324 (.448)	.470	-.740 (.572)	.196
PRS Lack of Executive Function	-.012 (.387)	.976	.468 (.404)	.247	-.238 (.470)	.612	**-.961 (.484)**	.047
TRS Lack of Anger Control	.221 (.437)	.614	.556 (.433)	.199	.205 (.353)	.561	**-1.012 (.457)**	.027
TRS Lack of Emotion Control	.162 (.577)	.778	.437 (.405)	.281	.235 (.406)	.564	**-1.365 (.542)**	.012
TRS Lack of Executive Function	.417 (.682)	.541	.369 (.443)	.405	.473 (.594)	.425	**-1.568 (.675)**	.020

Note. Unstandardized estimates and standard errors in parenthesis. Significant results are in bold. PRS = Parent Rating Scale; TRS = Teacher Rating Scale. Child age, child gender, mother age, maternal PTSD symptoms, maternal education level, and household income were controlled for in all models.

Table 6. Coefficient Estimates Examining the Effect of Parenting Behaviors on Dyadic Synchrony

	Mother Model				Child Model			
	Concurrent Synchrony		Lagged Synchrony		Concurrent Synchrony		Lagged Synchrony	
Parenting Behaviors	Estimate (SE)	*p*	Estimate (SE)	*p*	Estimate (SE)	*p*	Estimate (SE)	*p*
Directive	-.057 (.048)	.232	-.111 (.079)	.163	-.026 (.046)	.578	-.039 (.055)	.474
Negative Directive	-.787 (.455)	.084	**-**.511 (.889)	.565	-.772 (.599)	.197	**-2.445 (.808)**	.002
Positive Physical	-.094 (.061)	.123	**.189 (.097)**	.051	-.071 (.087)	.413	-.030 (.126)	.812
Negative Physical	.021 (.486)	.966	-.401 (.575)	.485	.070 (.328)	.831	-.008 (.205)	.970
Anger/Disgust	-.056 (.054)	.301	**-.112 (.041)**	.007	-.029 (.056)	.603	-.033 (.071)	.637
Positive Affect	-.023 (.035)	.513	**-.045 (.022)**	.040	-.030(.034)	.387	.044 (.035)	.209

Note. Unstandardized estimates and standard errors in parenthesis. Significant results are in bold.

Table 7. Descriptive statistics for mother and child RSA by epoch during the problem-solving task at 1-year follow-up

	Epoch	N	Min	Max	*M*	*SD*
Child RSA	1	51	5.03	8.84	7.12	.94
	2	51	4.67	9.02	6.99	.99
	3	51	4.9	8.92	7.01	.92
	4	51	4.74	8.77	6.93	.93
	5	51	4.83	8.52	6.94	.87
	6	50	5.05	8.89	6.85	.84
	7	49	5.02	8.72	6.77	.85
	8	46	5.13	8.3	6.84	.83
	9	46	5.32	9.13	7.07	.87
	10	38	4.41	8.82	6.72	1.04
Mother RSA	1	51	3.41	8.97	6.30	1.15
	2	51	2.84	9.82	6.35	1.31
	3	51	2.38	8.91	6.31	1.31
	4	51	3.76	9.22	6.40	1.17
	5	51	4.02	9.32	6.39	1.23
	6	50	3.64	9.29	6.29	1.21
	7	49	4.47	9.72	6.30	1.26
	8	46	3.84	8.7	6.26	1.30
	9	46	3.12	9.03	6.19	1.33
	10	34	3.98	8.74	6.29	1.15

Table 8. Descriptive statistics and bivariate correlations of synchrony coefficients (concurrent synchrony and lagged synchrony) in mother model and child model at baseline and 1-year follow-up

	1	2	3	4	5	6	7	8
1.Con Sync C T1	—							
2.Lag Sync C T1	.80**	—						
3.Con Sync M T1	.15	.06	—					
4.Lag Sync M T1	.14	.01	.94**	—				
5.Con Sync C T3	-.41**	-.32*	.10	.12	—			
6.Lag Sync C T3	.40**	.29*	-.06	-.06	-.92**	—		
7.Con Sync M T3	-.07	-.10	.40**	.38**	.39**	-.06	—	
8.Lag Sync M T3	.02	.07	-.34*	-.29*	.08	-.10	-.13	—
M	-.03	-.05	-.02	.00	.02	-.02	.02	.04
SD	.02	.03	.06	.11	.05	.06	.09	.13

Note. Con Sync = Concurrent Synchrony; Lag Sync = Lagged Synchrony; C = Child Model (Mother-to-Child Effects); M = Mother Model (Child-to-Mother Effects); T1 = Baseline; T3 = 1-year follow-up.
**p* < .05. ***p* < .01. ****p* < .001.

Table 9. Descriptive statistics and bivariate correlations among Study 2 key variables

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1.Con Sync C T1	—															
2.Lag Sync C T1	.22*	—														
3.Con Sync M T1	.33**	.30**	—													
4.Lag Sync M T1	.17	.09	.16	—												
5.SUP T1	.12	.01	.08	-.07	—											
6.NONSUP T1	-.10	.11	-.02	-.04	-.18	—										
7.PRS Lack of AC T1	-.22*	-.23*	-.05	-.01	-.16	.27*	—									
8.PRS Lack of EC T1	-.24*	-.14	-.11	.00	-.18	.33**	.79**	—								
9.PRS Lack of EF T1	-.27*	-.22*	-.08	-.01	-.15	.26*	.86**	.83**	—							
10.SUP T3	.08	.06	-.01	.00	.60**	-.17	-.14	-.18	-.22	—						
11.NONSUP T3	-.25*	-.03	-.07	.00	-.21*	.73**	.14	.15	.10	-.17	—					
12.PRS Lack of AC T4	-.13	-.16	.00	.05	-.03	.20	.73**	.48**	.60**	-.09	.14	—				
13.PRS Lack of EC T4	-.21*	-.16	-.17	.00	-.23*	.20	.57**	.62**	.53**	-.12	.01	.67**	—			
14.PRS Lack of EF T4	-.11	-.21*	-.04	-.01	-.08	.10	.75**	.53**	.70**	-.04	-.03	.84**	.81**	—		
15.Child Age	.15	-.22*	-.24*	-.08	-.05	-.09	-.17	-.11	-.09	-.02	-.08	-.17	-.01	-.01	—	
16.Child Gender	.03	.05	.03	.05	-.07	.15	-.30**	-.18	-.30**	.04	.19	-.15	-.02	-.16	-.06	—
M	-.06	-.06	-.04	-.01	16.56	7.56	53.40	52.91	53.66	16.40	7.42	51.24	51.78	52.46	8.85	2.44
SD	.07	.09	.01	.09	1.97	1.67	8.57	10.13	8.89	1.96	1.67	7.87	9.33	8.43	2.64	.50

Note. AC = Child Anger Control; EC = Child Emotion Control; EF = Child Executive Functioning; PRS = Parent Rating Scale; Con Sync = Concurrent Synchrony; Lag Sync = Lagged Synchrony; C = Child Model (Mother-to-Child Effects); M = Mother Model (Child-to-Mother Effects); SUP = Supportive Emotion Socialization; NONSUP = Nonsupportive Emotion Socialization; Child Gender (2 = boys, 3 = girls); T1 = Baseline; T3 = 1-year follow-up; T4 = 2-year follow-up.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

Table 10. Descriptive statistics and bivariate correlations of baseline RSA and mean RSA during the problem-solving task at baseline and 1-year follow-up

	1	2	3	4	5	6	7	8
BL_Read_C	—							
BL_Read_M	-.21	—						
BL_PS_C_Mean	.83**	-.06	—					
BL_PS_M_Mean	-.23	.88**	-.07	—				
T3_Read_C	.60**	-.15	.46**	-.14	—			
T3_Read_M	-.03	.69**	.08	.69**	-.05	—		
T3_PS_C_Mean	.49**	-.05	.48**	.04	.73**	-.01	—	
T3_PS_M_Mean	-.08	.72**	.12	.72**	-.15	.91**	-.06	—
M	7.09	6.42	6.91	6.44	7.03	6.27	6.95	6.30
SD	1.07	1.03	.91	1.03	.95	1.06	.79	1.04

Note. PS = Problem-Solving task; BL = Baseline; T3 = 1-year follow-up.
**p* < .05. ***p* < .01. ****p* < .001.

Table 11. Intervention effects on mother-child physiological synchrony at 1-year follow-up

	Child-to-Mother Concurrent Synchrony				Child-to-Mother Lagged Synchrony				Mother-to-Child Concurrent Synchrony				Mother-to-Child Lagged Synchrony			
Predictors	*B*	*SE*	β	*p*	*B*	*SE*	β	*p*	*B*	*SE*	β	*p*	*B*	*SE*	β	*p*
Corresponding synchrony coefficients at T1	-1.35	.42	-.46	.000	.63	.28	.32	.019	.42	.21	.27	.043	-.22	.17	-.21	.174
ITT	.01	.02	.13	.326	-.03	.02	-.21	.114	.00	.02	-.01	.944	-.02	.04	-.07	.619
Child Age	.00	.00	.13	.403	.00	.00	-.07	.656	.00	.01	.05	.745	.00	.01	-.06	.672
Child Gender	.01	.02	.13	.350	-.03	.02	-.20	.141	-.01	.02	-.07	.611	.04	.04	.15	.300
Years of Marriage	.00	.00	-.05	.779	.00	.00	.02	.914	.00	.00	.25	.118	.00	.00	-.01	.968
Education	-.01	.01	-.11	.480	.01	.01	.20	.224	.00	.01	.02	.912	-.01	.02	-.10	.569
Income	.00	.00	.18	.346	.00	.00	-.05	.802	.00	.01	.14	.463	-.01	.01	-.14	.521
Deployment Status	.02	.04	.08	.590	-.02	.05	-.06	.728	-.01	.07	-.01	.945	.01	.10	.01	.949
R^2	.23				.19				.27				.15			

Note. ITT (0 = control, 1 = intervention); Child Gender (2 = boys, 3 = girls); Deployment Status (0 = non-deployed, 1 = deployed).

Table 12. Standardized coefficients indicating the indirect effect of the ADAPT on child self-regulation at 2-year follow-up through parental emotion socialization.

Outcome Variable		Lack of Anger Control		Lack of Emotion Control		Lack of Executive Function	
Mediator	Estimated Path	β	*p*	β	*p*	β	*p*
Supportive Emotion Socialization	a Path	.10	.264	.10	.245	.09	.263
	b Path	.05	.523	.11	.238	.19	.009
	Indirect Effect	.01	.577	.01	.405	.02	.299
Non-Supportive Emotion Socialization	a Path	-.18	.008	-.17	.012	-.17	.012
	b Path	.18	.017	.02	.866	.04	.660
	Indirect Effect	-.03	.079	-.00	.867	-.01	.666

Note. A Path = ITT → parental emotion socialization; b Path = parental emotion socialization → child self-regulation.

Table 13. Moderation effect of physiological synchrony on the mediated effect of ADAPT on child lack of anger control through mother's non-supportive emotion socialization.

Moderator	Model Fit CFI	SRMR	RMSEA	Moderation Effect on a Path	Moderation Effect on b Path
Concurrent Synchrony in Child Model	.974	.011	.112	β = .45 (*p* = .001)	β = -.23 (*p* = .016)
Lagged Synchrony in Child Model	.951	.139	.042	β = .08 (*p* = .557)	β = -.14 (*p* = .116)
Concurrent Synchrony in Mother Model	NA	.020	NA	β = .42 (*p* = .287)	β = -.11 (*p* = .262)
Lagged Synchrony in Mother Model	1.000	.035	.000	β = .07 (*p* = .558)	β = .11 (*p* = .137)

Note. A Path = ITT → non-supportive emotion socialization; b Path = non-supportive emotion socialization → child lack of anger control.

Figure 1. RSA trajectories during the problem-solving task for mother (panel A) and child (panel B) at baseline

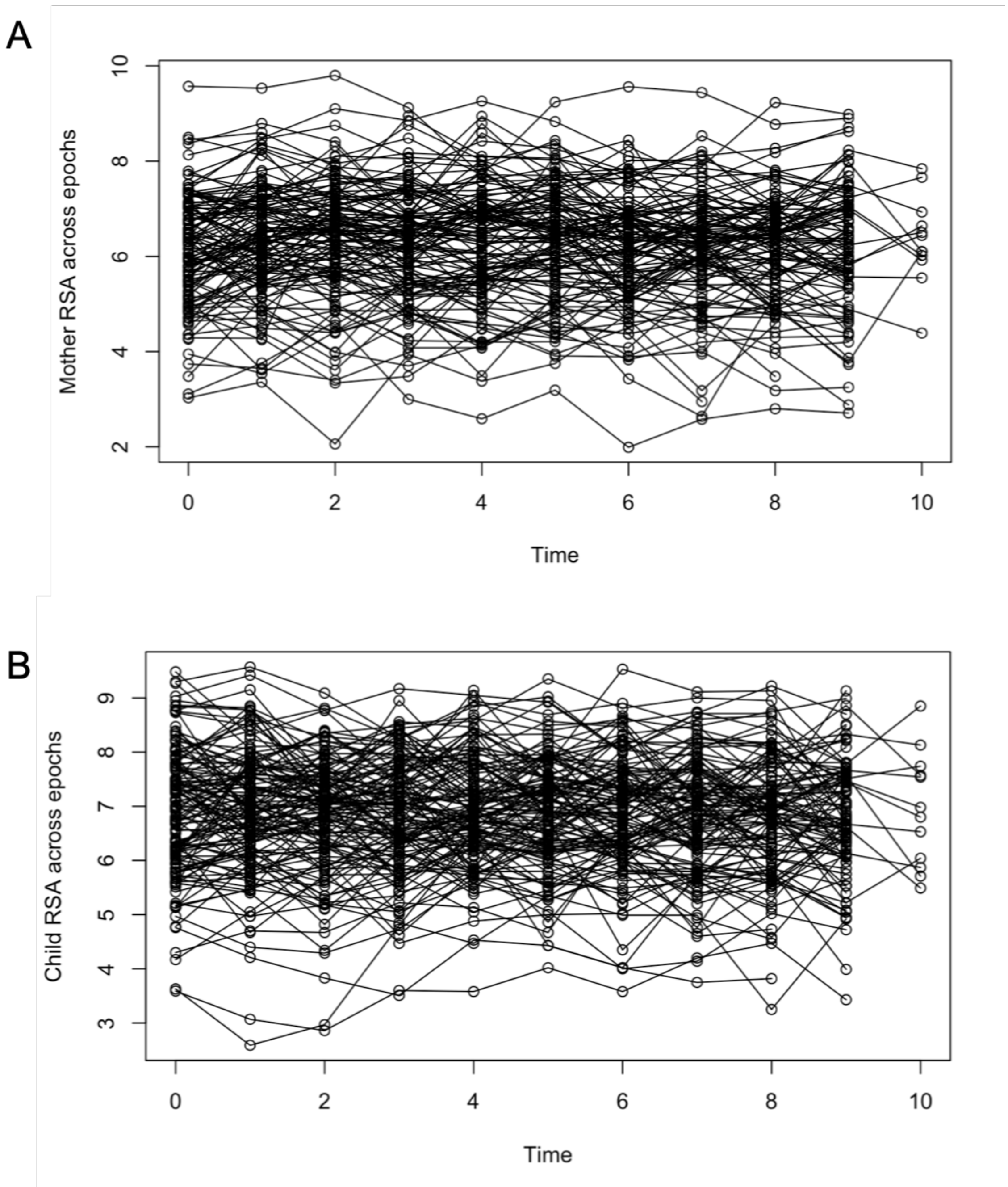


Figure 2. Examples of parent-child dyadic RSA demonstrating positive (panel A) and negative (panel B) synchrony at baseline

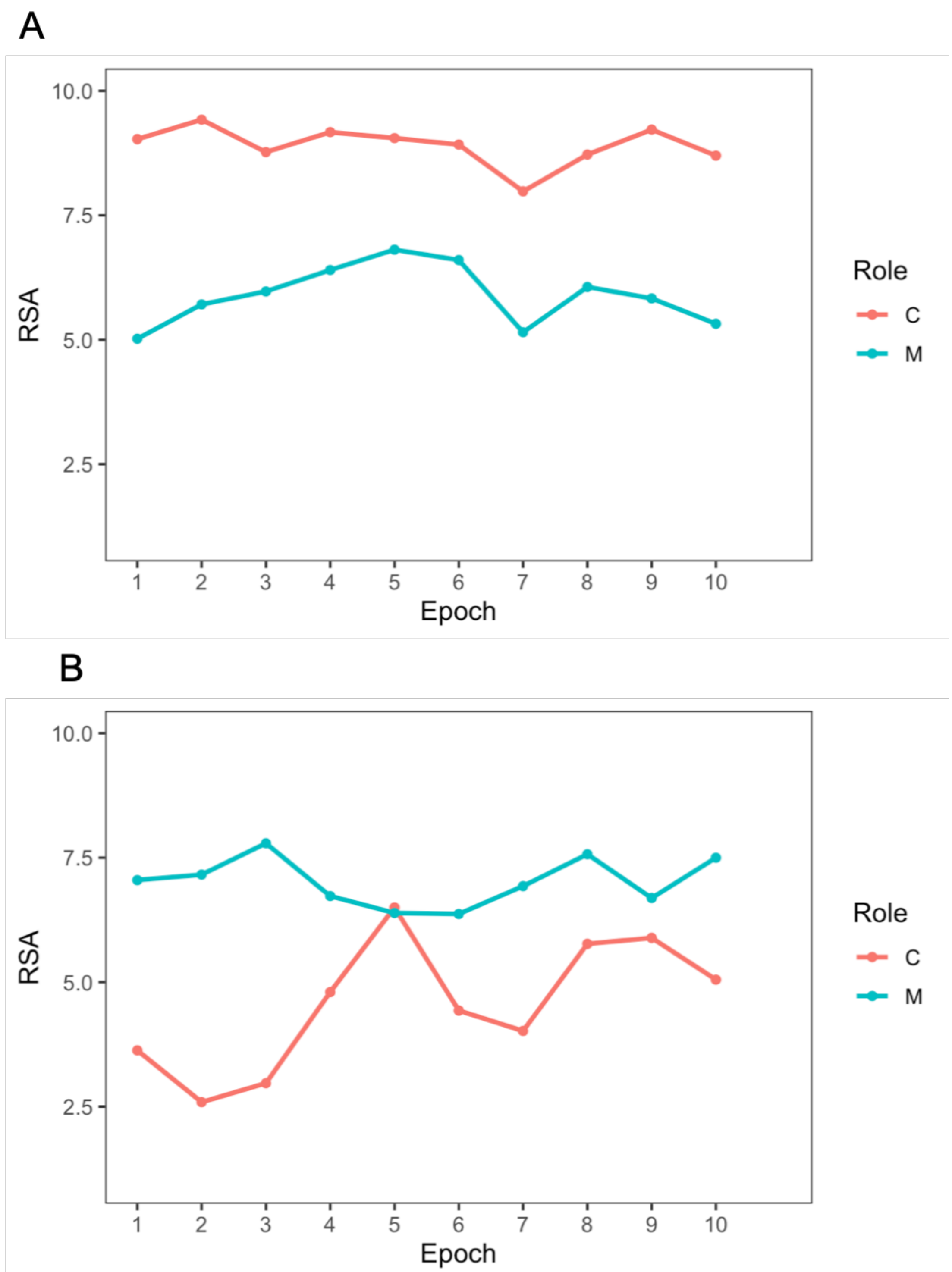
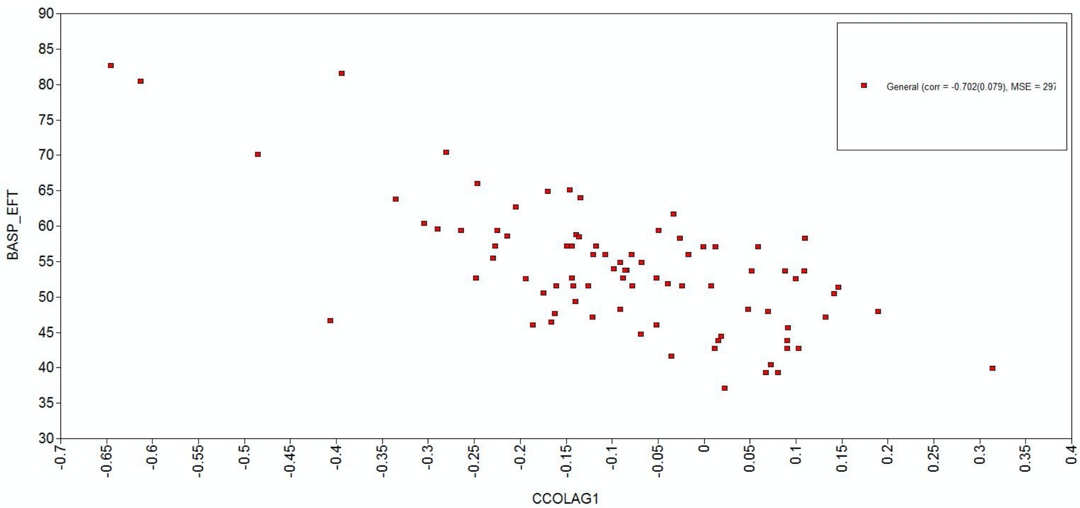
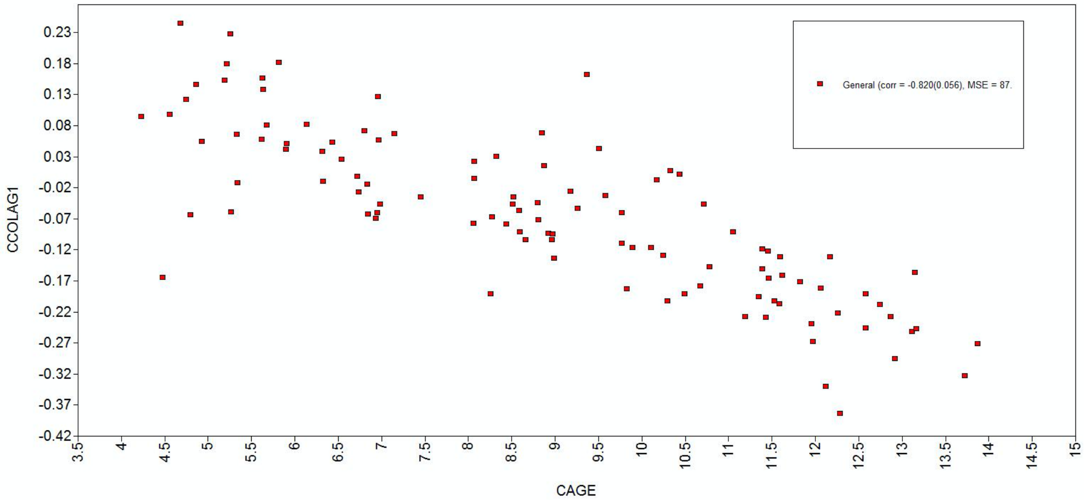


Figure 3. Sample Scatterplot Presenting the Association Between the Latent Slope Indicating Lagged Synchrony in Child Model and Parent Reports on Child Lack of Executive Functioning



Note. CCOLAG1 = The Latent Slope Indicating Lagged Synchrony in Child Model; BASP_EFT = Parent Reports on Child Lack of Executive Functioning.

Figure 4. Sample Scatterplot Presenting the Association Between the Latent Slope Indicating Lagged Synchrony in Child Model and Child Age



Note. CCOLAG1 = The Latent Slope Indicating Lagged Synchrony in Child Model; CAGE = Child Age.

Figure 5. The Region of Significant Plot Reflecting the Moderation Effect of Child Age on the Association Between Concurrent Synchrony in Child Model and Child Lack of Executive Functioning

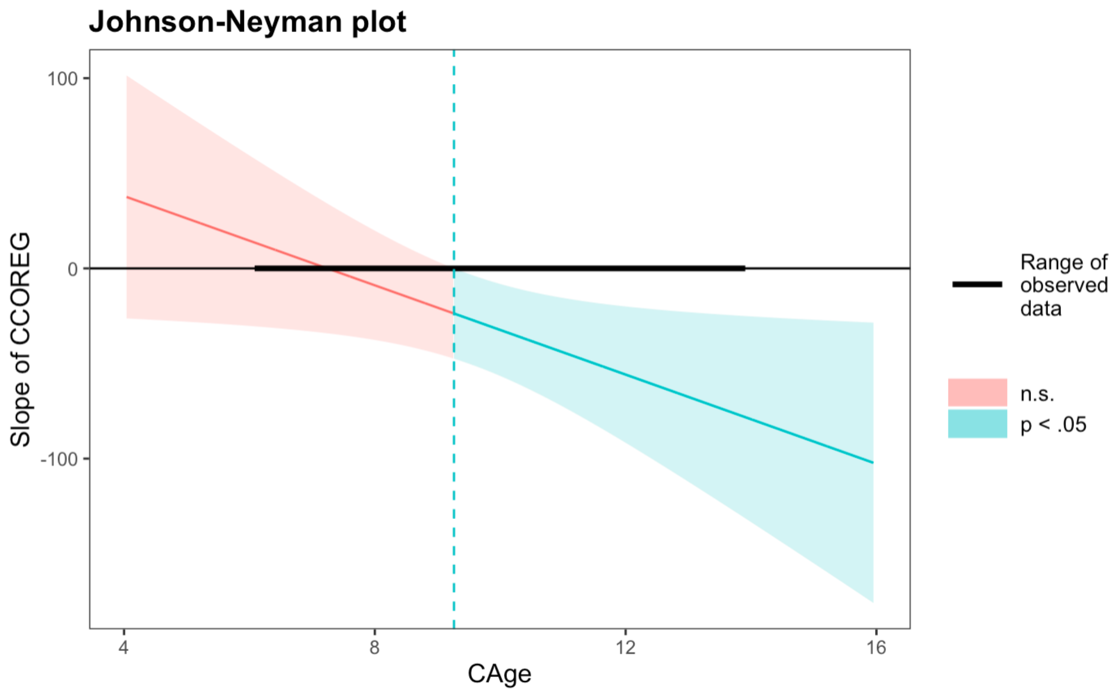


Figure 6. Conceptual model illustrating the research question on the moderation role of parent-child physiological synchrony

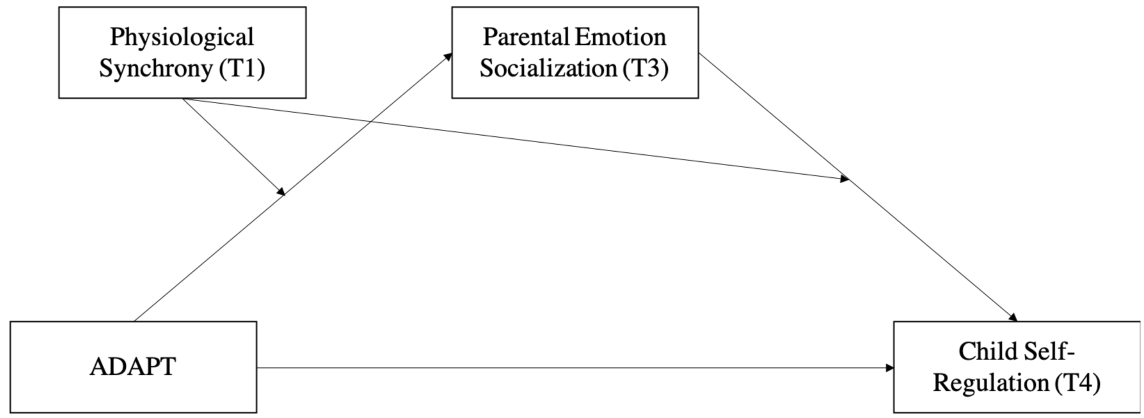
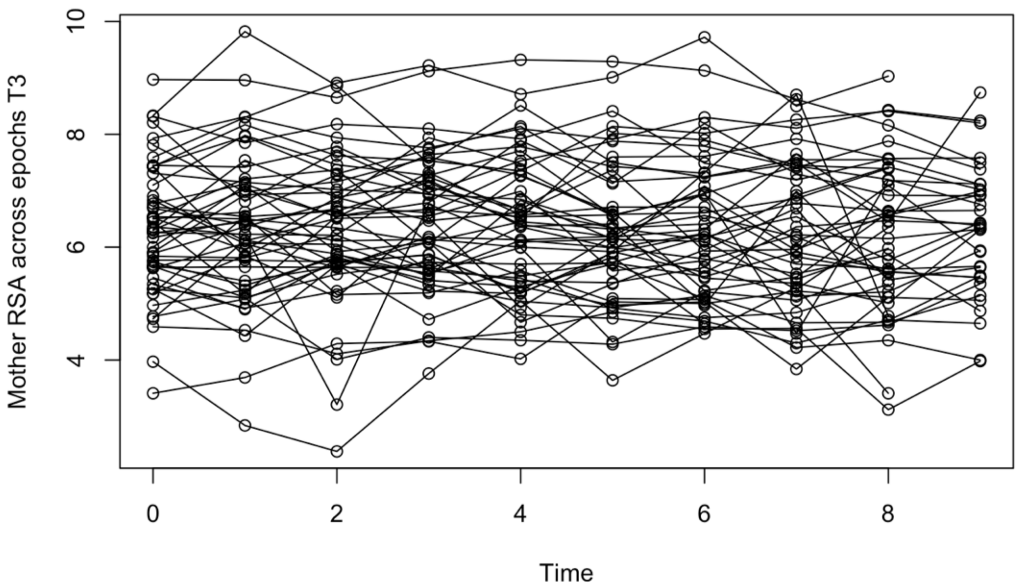


Figure 7. RSA trajectories during the problem-solving task for mother (panel A) and child (panel B) at 1-year follow-up

A



B